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Original Communications

STAGED OCCLUSION OF THE CORONARY ARTERIES AND STUDIES UNDER LOW OXYGEN TENSION

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INTRODUCTION

It has long been the hope of investigators working with coronary artery occlusion to develop a method of gradually occluding the arteries in dogs over a period of time, thus simulating coronary artery disease in man. Various methods of occlusion have been attempted and described. These include the use of small metal bands,[1] reactive materials such as cellophane,[2] various methods of ligature,[3, 4] and several ingenious clamps.[5-8] The major difficulties with most of these methods have been the problem of gauging the degrees of occlusion of the vessel and the difficulty encountered in producing final complete occlusion. The purpose of this paper is to present a method of producing staged occlusion of the coronary arteries together with the electrocardiographic changes which occur when these dogs are placed on decreased amount of oxygen.

METHODS

Small silver clamps of the type used by Goldblatt[9] for the experimental production of renal hypertension were used (Fig. 1). During the course of a series of experiments on revascularization of the heart by means of cardiojejunopexy,[10] these clamps were applied to all major branches of the coronary arteries in a large number of dogs. The technique of gradual occlusion was

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applied in the following manner: after the chest had been opened in the anesthetized dog, the clamps were applied about the desired vessel. The vessel was then occluded to the desired amount by tightening the screw a number of turns selected to produce the desired degree of occlusion. This amounted to 3½ turns for partial occlusion with the 3 mm. clamp and 2½ turns for partial occlusion with the 2 mm. clamps. Two to four weeks later the dogs were re-operated upon, and the clamps were completely tightened Auricular appendage amputation at the time of the original placement of the clamps facilitated later dissections.

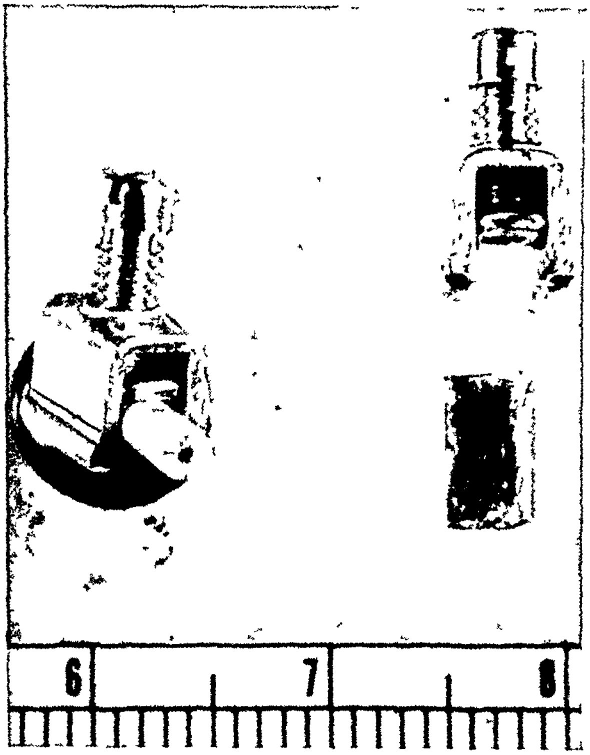

Fig 1.—Goldblatt clamp on plastic tube simulating placement on coronary artery.

In order to demonstrate the effect of the occlusion, electrocardiograms were made, using the method of Kimura.[11] After partial or complete coronary artery occlusion was produced in 15 dogs, the effect of low oxygen tension on them was studied. This was done by taking electrocardiograms before and immediately after the animal was placed on a 10 per cent oxygen mixture for ten minutes. Post-mortem examinations of the coronary vessels were made when the animals were sacrificed or died spontaneously.

RESULTS

In a series of 15 normal dogs in which the anterior descending artery was occluded in stages as described, there were nine deaths. Six of the nine deaths occurred after the artery was completely occluded. In addition, the clamps were used on another series of 65 dogs on which cardiojejunopexies had been done.

The changes produced on the electrocardiogram by partial narrowing of the anterior descending artery were: an elevation of S-T$_1$ and a depression of S-T$_2$ and S-T$_3$. With complete occlusion of the vessel, these changes were usually accentuated (Fig. 2).

When placed on a gas mixture containing 10 per cent oxygen, 12 of 15 dogs with complete occlusion of one or more coronary arteries showed depression of the T wave or S-T changes (Fig. 3). Fifteen stock dogs were checked in a similar manner and only 1 showed any change in the T or S-T segment (Fig. 4).

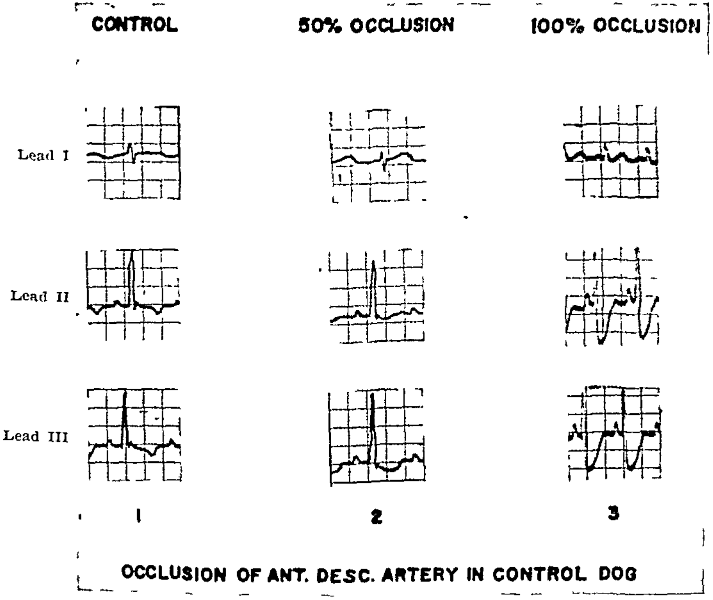

Fig. 2—Changes produced on the electrocardiogram by partial and complete narrowing of the anterior descending artery.

Post-mortem studies after complete tightening of the clamps failed to reveal evidence of residual lumen in the coronary artery. In the normal control dogs, coronary artery occlusion with the Goldblatt clamp in stages did not significantly lower the mortality rate as compared with acute ligations.

DISCUSSION

In order to simulate human coronary artery disease more closely, it has been felt that gradual occlusion is preferable to acute coronary artery ligature. In attempts to evaluate the effectiveness of revascularization procedures, staged occlusion is especially valuable. Acute ligature may be unsatisfactory

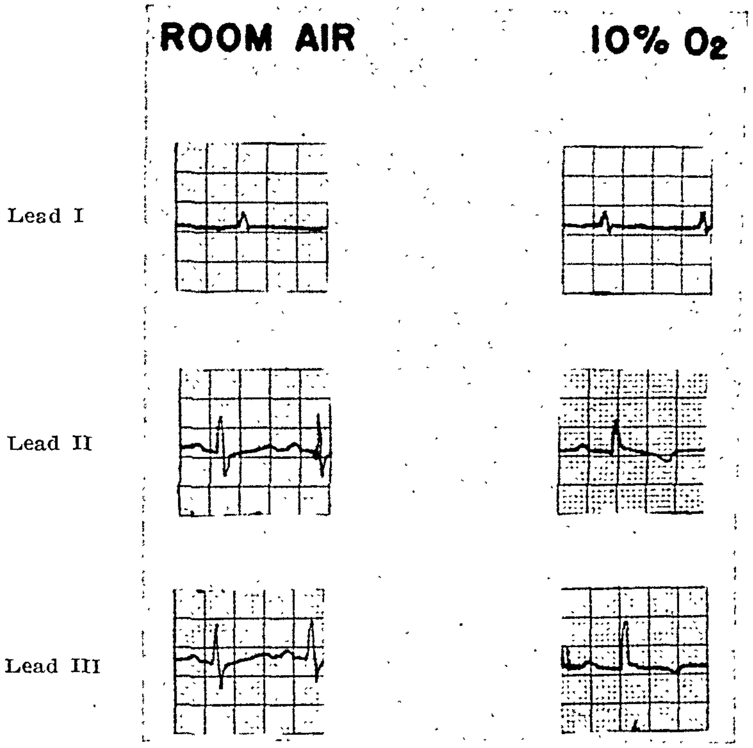

Fig. 3.—Control Dog. Changes produced in the electrocardiogram of a dog with complete occlusion of one or more coronary arteries when respired on a gas containing only 10 per cent oxygen for ten minutes.

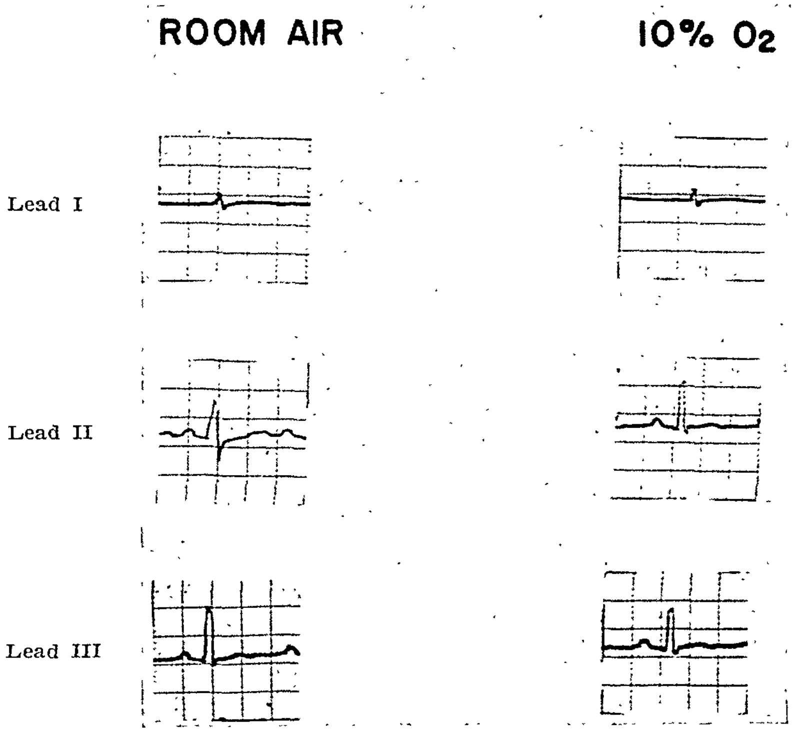

Fig. 4.—Normal Dog. Absence of changes on the electrocardiogram of stock dogs when spired on a gas mixture containing only 10 per cent oxygen for ten minutes.

as a true test of revascularization experiments, as there is no reason why collaterals that do develop should take over immediately following the acute tie-off. In addition, this method should be valuable in providing material for studies of pathologic and physiologic changes of predetermined degrees of coronary artery occlusion.

The Goldblatt clamp has been of definite value in our studies of experimental coronary artery occlusion and myocardial revascularization. The presence of the screw on the top facilitates locating the clamps at subsequent operations and also makes it possible to regulate the degree of narrowing of the artery at each stage. We feel that the use of this method of coronary artery occlusion has been a valuable adjunct in our studies of coronary artery disease and revascularization of the heart. The changes produced with anoxemia are probably similar to those produced by the anoxemia[12] or the Master two-step test[13] in the human. The anoxemia changes which are usually reversible might be exceedingly useful as a means of measuring the therapeutic effectiveness of various drugs used commonly for angina or coronary thrombosis in the human.

SUMMARY AND CONCLUSION

1. A method of producing staged occlusion of coronary arteries in the experimental animal has been presented.

2. It is felt that the Goldblatt clamp is a particularly valuable tool in the study of experimental myocardial revascularization and coronary artery occlusion.

3. Dogs with experimentally produced coronary artery occlusion quickly develop changes on the electrocardiogram when put on a gas mixture containing 10 per cent oxygen for ten minutes.

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SURGERY OF EVENTRATION OF THE DIAPHRAGM

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ALTHOUGH a gross misnomer, "eventration of the diaphragm" is the clinical term accepted by usage to describe an abnormally high position of the intact diaphragm.

This condition is a congenital abnormality and the term eventration should not be used in conditions where the phrenic nerve is paralyzed, either by a trauma, new growth, or as a result of a neuritis. The diagnosis of eventration should never be made if there is frank paradox of the diaphragm on deep, quick inspiration. The condition is still a rarity in comparison with many other diaphragmatic defects, particularly hiatal hernia, but since the inception of mass x-ray more cases have been discovered. Even so, in the last five years the Southampton and Portsmouth Mass X-ray Units have diagnosed only 32 cases in 412,000 subjects. This is an instance of 1 in 1,400 approximately. Another 6 cases have been seen independently in this Unit.

Reports of the surgical correction of eventration of the diaphragm are equally rare since less than 20 have been reported in the English literature up to 1953. Because of this, we feel that our experience of 5 patients with eventration of the diaphragm treated successfully by surgery is worth recording.

Etiology and Pathology.—We agree with Boyne-Jones (1916), Clopton (1923), and Beck (1950) that this is a congenital abnormality. Eventration results from a failure of muscularization of the diaphragm. This may be localized or the whole dome may be involved, in which case the diaphragm is represented by a thin, diaphanous membrane attached peripherally to normal muscle. In the so-called acquired eventration, such an arrangement does not exist, but the diaphragm shows a normally developed muscle and a normal central tendon; the only abnormality is that the muscle is extremely atrophic and the phrenic nerve is small, which, when faradically stimulated causes no contraction of the diaphragm. In true eventration the phrenic nerve appears normal and the muscular portion of the diaphragm contracts vigorously on faradic stimulation of the nerve and by its contraction pulls down the maldeveloped portion.

It is often stated that there are associated congenital abnormalities and that this is a point in favor of eventration being a congenital defect. In the total cases reviewed, however, this has not been so. In one case only was there an associated abnormality in the form of a foramen of Morgagni hernia.

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In our experience, a localized eventration, even though less common, is more likely to cause symptoms. Of the surgical cases, in only 1 was the whole dome involved. Of 38 cases under review, 3 only had a right-sided eventration and in 1 of these 3 the eventration was bilateral. This marked selection of the left side has been commented on by Sanford (1953) (Fig. 1).

Clinical Features.—In the series there was no disparity between the sexes, of those cases discovered by mass x-ray, 15 were males and 17 females and of the 5 patients operated upon, 3 were males and 2 were females Eventration may be detected at any age; the range in our group was from 13 to 72 years

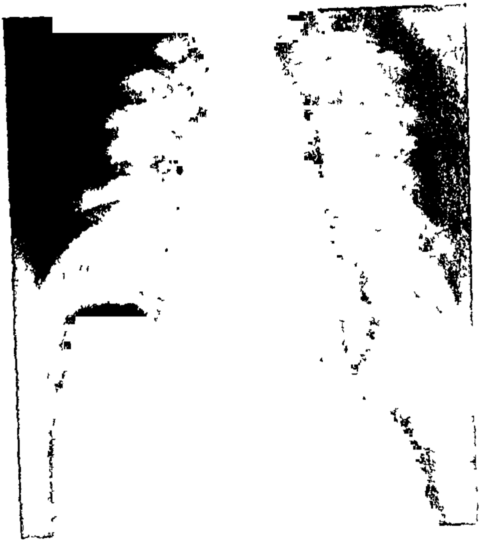


Fig 1 —A right-sided eventration is shown On screening there was seen to be a small localized left eventration The patient was symptom-free

There is no definite clinical picture by which the diagnosis can be made. In the newborn, eventration may cause death from cardiorespiratory failure, which may be attributed to congenital heart disease or pulmonary atelectasis However, it is due to a failure of the infant to oxygenate adequately because of impaired diaphragmatic movement, added to which the hemithorax may be considerably reduced by space-occupying gut. Cardiac displacement may also be present, adding to the child's difficulties (Ravitch and Handelsman, 1952). Infantile eventration may not be as frequent as was previously thought and certainly by our definition of an eventration the numbers reported are probably excessive, for example, Bingham (1954) reports 2 cases of severe respiratory distress, but both had paradoxical movement of the diaphragm and, at operation, they were anatomically normal and eventually recovered normal movement. Both babies had been breech presentations. These, of course, were not cases of eventration but of birth injuries to the phrenic nerve.

Once beyond infancy the condition tends to remain symptomless until adult life when increasing weight and raised intra-abdominal pressure may produce symptoms. All cases with symptoms had left-sided defects. These are usually gastrointestinal but there may be associated respiratory embarrassment and even cardiac distress. Six of the 38 patients presented with symptoms which were gastrointestinal and included epigastric pain, flatulence, belching, and 1 had severe melena; this patient will be discussed later. The abdominal pain may not be relieved by alkalis and is made worse by food, in contrast to the pain of peptic ulcer. This pain is sometimes characteristically relieved by the patient lying on the right side. The explanation for this is readily seen from he barium studies. The only constant physical findings were audible bowel sounds in the left chest and displacement of the heart into the right hemithorax, so-called dextrocardia (Fig. 2) These findings are not confined to ventration and the diagnosis ultimately depends upon fluoroscopic and barium udies.

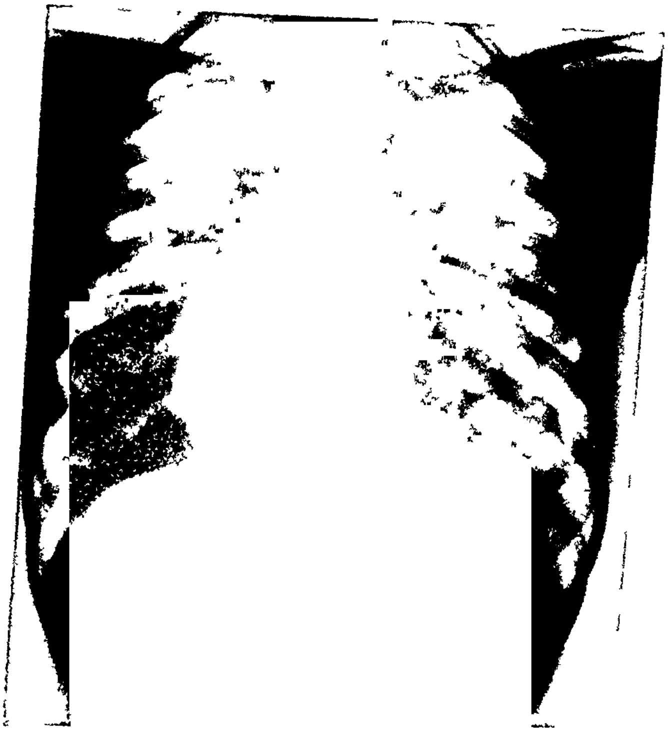


Fig. 2—Typical findings in eventration with displacement of the heart to the right This patient had an associated parasternal defect also

Radiographic Findings.—Conspicuous elevation of the diaphragm which resents a smooth unbroken curve is said to be one of the cardinal diagnostic atures of complete eventration. If the defect is localized, a cystic shadow ay be reported

In all cases screened (one third of the series), the diaphragm was mobile, though often limited in its range of movement. The final movement was always downward on sniffing and the eventration itself presented a dicroticlike pattern. The reason for this is obvious for, as the peripheral muscular ring contracts, the lax eventrated portion does not take up quickly and in some cases might move initially in a paradoxical manner. There is some delay before the muscle takes up the lax membranous portion, which due to the rising positive intraabdominal pressure and negative intrapleural pressure, travels up, but this is checked as the normal peripheral muscle takes up the slack. Its final movement therefore is always downward. This concurs with Evans and Simpson (1950), and Bisgard (1937).

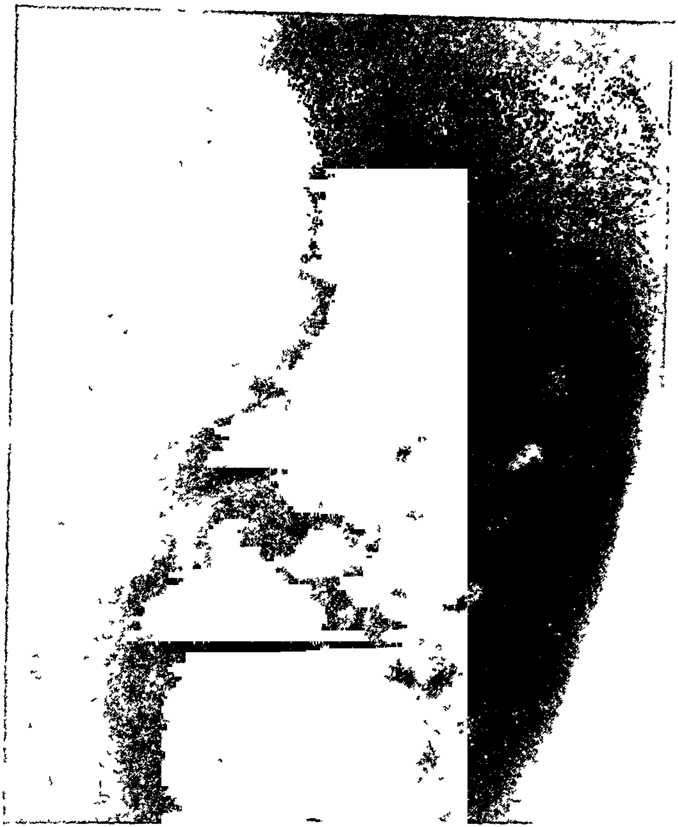
This point is borne out, a patient whose history and x rays were suggestive of eventration, but whose whole diaphragm was markedly paradoxical through all stages on screening. Because of troublesome gastric symptoms a surgical repair was carried out and it was seen that the phrenic nerve was atrophic. The diaphragm failed to contract after faradic stimulation of the nerve and examination of the diaphragm itself showed that all the normal components were present but the muscular portion was atrophic. This case would fall into the group of so called acquired eventrations.

Barium meal and enema are frequently diagnostic as they may demonstrate the stomach rolled upside down with the splenic flexure alongside lying beneath the intact dome of the diaphragm. There is no reflux of barium up the esophagus in the Trendelenburg position. In our patients, the stomach emptied rapidly with the patient lying on the right side, which explains the relief from pain obtained by this maneuver. In all patients the stomach appeared larger than normal and this could be conducive to hemorrhage and volvulus. The only condition with which eventration of the diaphragm could be confused is a hernia through the dome of the diaphragm. Screening and radiography will often fail to differentiate the two. This sort of defect on screening will give a similar pattern to that found in eventration (Figs. 3 and 4).

Treatment.—In the past it has been stated that there is no place for surgical treatment. In the majority of cases, treatment is unnecessary but in those people who have symptoms surgery should be undertaken. We also advise correction in young patients with a gross abnormality because a physiologic operation can easily be performed and the fault corrected.

If the defect is localized, there is no problem. This merely means resection of the membrane and suturing of the muscular components, care always being taken not to jeopardize the lateral division of the phrenic nerve. When the whole dome is involved, surgical repair at first may appear formidable, but complete mobilization of the muscular component can be carried out, and after resection of the defective portion, muscle to muscle suture performed. A careful dissection around the chest wall and the pericardium is imperative, mobilizing the muscular portion of the diaphragm to its fullest extent. This muscular portion is often well hidden and appears almost to be covered by its own membrane. Once it is fully mobilized, the affected portion of the diaphragm

Fig. 3.



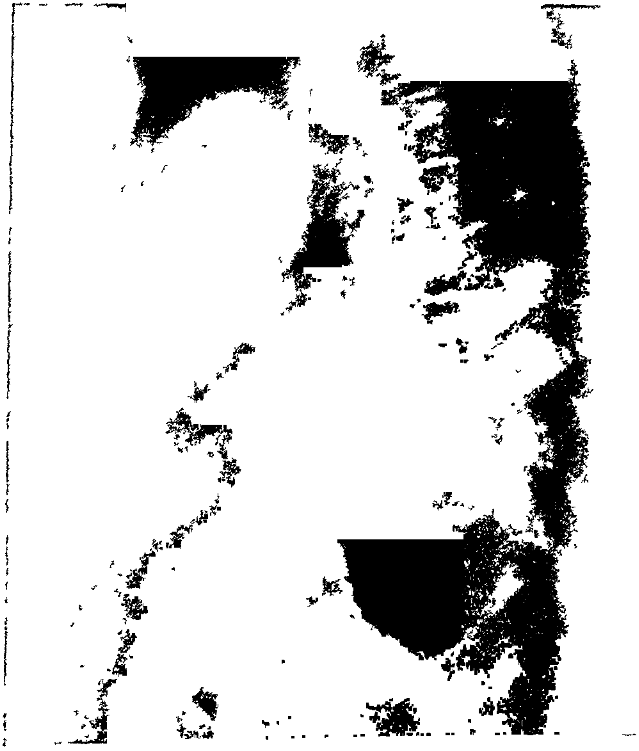
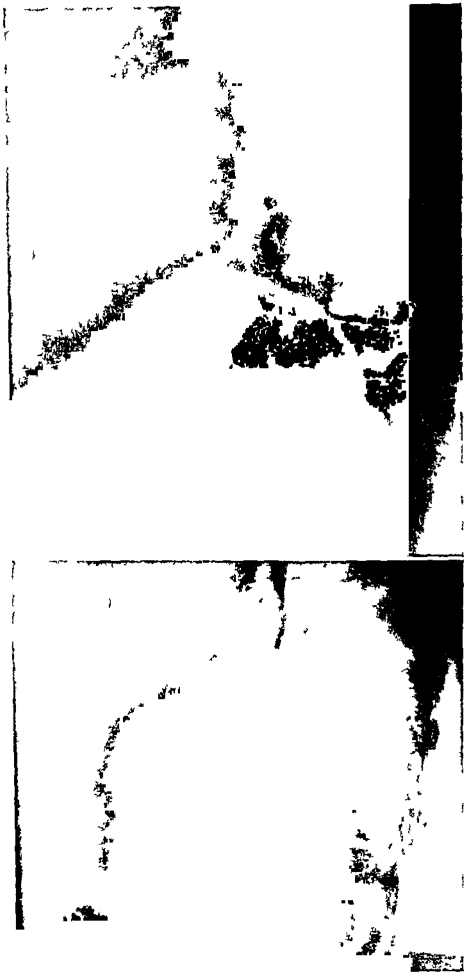


Fig. 4.

Figs. 3 and 4.—These x-rays show a lateral view and barium studies of a case of hernia through the dome of the diaphragm. It is extremely difficult to tell this from an eventration, *preoperatively*.

A



B

Fig 5.—Case 1 *A* and *B*, Lateral films with excessive resting gastric contents The barium studies show the rotation of the stomach upward Following repair, barium studies showed the stomach lying normally

can be resected and muscle-to-muscle suture performed. In none of these cases was it difficult to obtain muscular apposition, and postoperative screening showed an intact diaphragm with limited but normal movement on respiration. No reinforcement such as tantalum mesh or fascia lata grafts is necessary.

CASE REPORTS

CASE 1.—The patient, a man aged 43 years, whose symptoms began at the age of 31. He complained then of acute indigestion with pain radiating to the back. This acute epigastric pain persisted and was not particularly related to food. It was never relieved by medicines and after a meal there was troublesome flatulence. He always had a sensation of fullness in the stomach and this was aggravated if he sat up very long. When first seen his symptoms had progressed and the only way he could get relief was by lying down in bed. There was no history of dyspnea on exertion. The membranous portion of the diaphragm was resected, the peripheral muscle mass mobilized extensively and muscle-to-muscle suture performed. Since the operation he is free of symptoms. Postoperative barium studies show that the stomach is lying normally and the diaphragm moves down on inspiration (Fig. 5, *A* and *B*, and *C*).

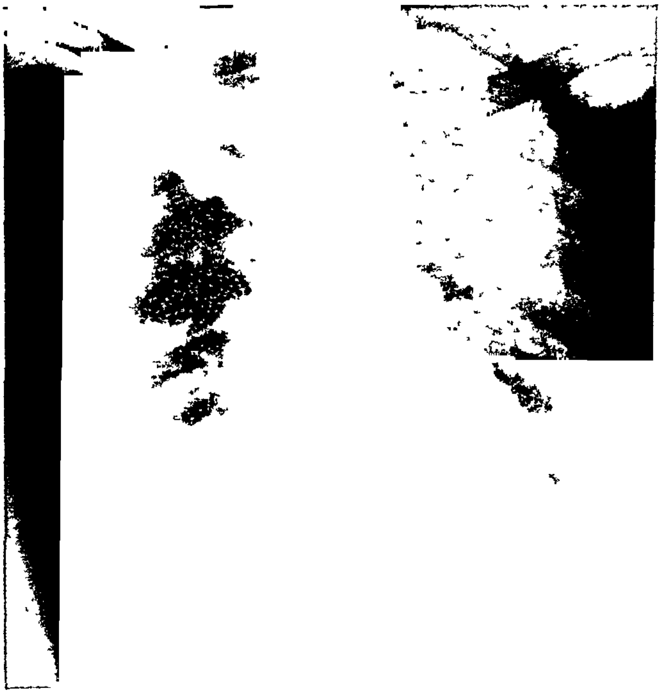
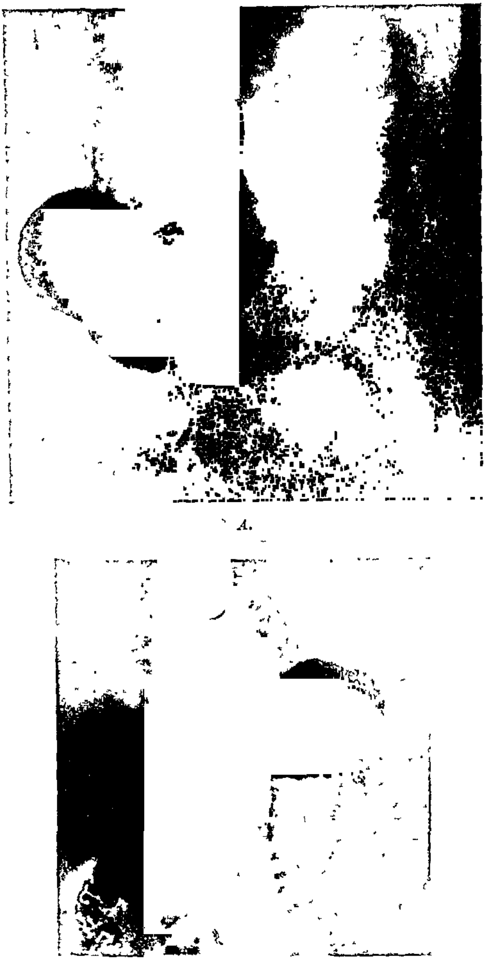


Fig. 5.—*Cont'd.* *C*, Posteroanterior film showing the diaphragm lower on the left side than on the right.

CASE 2.—The patient was a man, aged 67 years. One year prior to operation he had a melena of such severity that a tranfusion of 4 pints of blood was required. He was otherwise symptom free at the time. Barium studies then showed an eventration with typical rotation of the stomach and no evidence of gastric or duodenal ulceration. Three months later he developed sharp pains in the epigastrium and the right hypochondrium occurring one-half hour after meals. Lying on the right side relieved the pain. At this time he noticed dyspnea which progressed until, upon admission, it was so severe that he could not walk and talk at the same time. He had epigastric pain, flatulence, and a feeling of distention in the abdomen as if "blown up with wind." This was always relieved by lying on the right



A.

B.

Fig. 6.—Case 2 This patient had severe and repeated melena and gastrostaxis. *A* a
B, Pre- and postoperative barium studies with typical rotation of the stomach upward. F
lowing repair, the stomach lies and empties normally.

side. He had had several more small melena prior to admission and one while awaiting operation. In recent years he had been gaining weight and had put on nearly 28 pounds. Screening showed there was no true paradox and in the final phase of inspiration the site of the eventration moved downward. Thoracotomy revealed a localized eventration entirely surrounded by a muscular ring. The defect was excised and good apposition of muscle to muscle obtained. Since operation the symptoms have been completely relieved. Figs. 6*A* and 6*B* show pre- and postoperative barium studies.

CASE 3.—A boy, aged 13 years, had no symptoms but it was felt that such an extensive defect warranted repair (Fig. 2). At thoracotomy, there was an area of eventration about 5 inches in diameter surrounded by a good muscular rim. Medial to the muscular rim was a small parasternal defect which contained extraperitoneal fat. Apposition of muscle to muscle was simple and postoperative studies showed that the diaphragm moved normally.

The other cases in which operation was performed presented no technical difficulties and restoration of muscle to muscle was obtained. Postoperative screening showed a mobile, intact diaphragm.

SUMMARY

Surgery of eventration of the diaphragm is discussed and while 32 cases were seen only 5 required surgery for symptoms.

It is felt that the use of foreign bodies is unnecessary in the repair of this defect, for with adequate mobilization of the muscular portion of the diaphragm, muscle-to-muscle suture can be performed after resection of the defective portion.

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MULTIPLE RIB FRACTURE WITH INSTABILITY OF CHEST WALL

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DURING the past fifteen years there has been a marked improvement in the mortality and morbidity rates of patients with multiple rib fractures This change has been brought about largely as a result of a better understanding of respiratory physiology by the medical profession and the control of infections by the antibiotics A thorough understanding of the mechanics of respiration, the alterations which take place following injury, and the correction or, preferably, prevention of these changes is more important than any surgical technique for fixation of fractured ribs We should like to emphasize in particular the importance of (1) early relief of pneumothorax by insertion of a large intercostal catheter (No 28 or 30 F, Foley), (2) temporary stabilization of an instable chest wall by external traction, (3) removal of blood from the pleural cavity when present in significant quantity, (4) replacement of blood volume to normal level, (5) nasotracheal suction every hour, which must stimulate cough to be effective, (6) tracheotomy if nasotracheal suction is not effective or practical, and (7) intercostal nerve block anesthesia if possible, however, many patients have extensive bilateral fractures or other complications which make this impractical at times

After accomplishing the stabilization of the patient and ascertaining that there are no ruptured viscera or other injuries necessitating prior treatment, one should then consider permanent stabilization of the chest wall, if there is significant paradoxical motion of the chest wall, or if there is a considerable deformity of the chest due to the fractured ribs Twenty four hours is usually sufficient for evaluation and stabilization of the patient

The treatment of multiple rib fractures with paradoxical motion or deformity of the chest has not kept pace with advances in other branches of thoracic surgery There are three reasons for desiring an improved method for treating such injuries (1) competent investigators[1] [2] have shown that a mortality rate of 10 to 20 per cent exists in patients having rib fractures associated with pleural or lung complications, (2) the long period of immobilization in bed with the traction technique, as advocated by Heroy and Eggleston,[3] has many associated complications, and (3) last, but not least, the economic factor of prolonged hospitalization and time lost from the patient's occupation demands a method of quicker rehabilitation of the patient We shall describe in this report a method of treatment which we think is an improvement on existing methods and has worked satisfactorily in our hands

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Blades and Kent,[4] in 1940, advocated the simple expedient of drilling holes in the ends of sectioned ribs and securing them with silk ligatures as a method of fixing ribs at points of division. Klassen,[5] in 1949, advocated medullary pegging with autogenous medullary rib pegs as a method of obtaining a pain-free stable thorax following thoracotomy. Coleman and Coleman,[6] in 1950, advocated a method of wire fixation of the rib fragments. Overholt and Kenny,[7] in 1952, devised a mortise and tenon fixation of divided ribs.

We have found that the stabilization of the flail chest can best be accomplished by the use of the intramedullary Rush nail. Wiring the fragments as advocated by Coleman and Coleman has been used where intramedullary fixation is not practical.

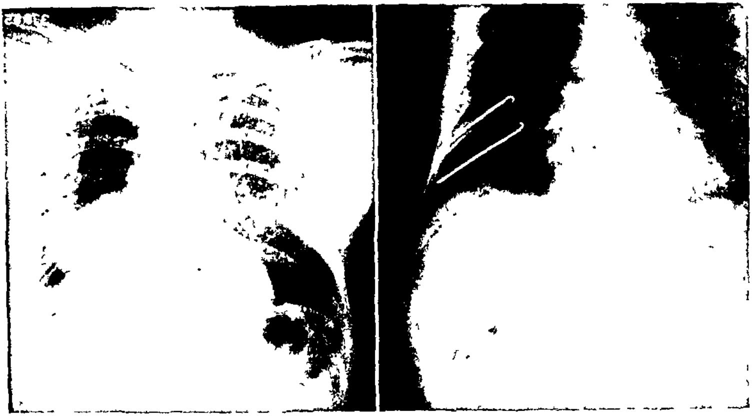
We have used both general and local anesthesia with equally good results. General anesthesia through an endotracheal tube has been the method used in most cases, and should be chosen if any intrathoracic work is likely. In a few patients we have used intercostal nerve block and local infiltration anesthesia where there was little or no pneumothorax or hemothorax. Although at least a small opening in the pleura is usually made during the procedure, the patient, with an intercostal tube in the pleural cavity which is attached to a water-seal bottle, can keep the lung expanded by coughing and blowing against the cheeks.

The technique employed is to use a generous incision parallel to the ribs and over the center of maximal deformity or maximal paradoxical motion. The fractured ribs are exposed and a drill hole is made approximately 3 to 4 cm. from the ends of the fragments. The smallest diameter intramedullary nail of the Rush type, 6 to 8 cm. long, is then inserted so that the bevel of the nail will follow the contour of the rib. Wire sutures may be used for some of the upper ribs which are not accessible through the incision. In our cases, three nails have been sufficient to give adequate stabilization of the chest, regardless of the number of ribs fractured. Often only two nails and sometimes only one nail, properly placed at the center of an area of paradoxical motion, will adequately stabilize the ribs. It is probably best if possible, however, to use two or three nails as one will sometimes become loosened by severe coughing.

The advantages of this procedure are: (1) it gives better stability than other methods previously advocated, (2) the amount of pain that the patient has is greatly diminished, (3) much better anatomical approximation of the rib fragments can be obtained by this method, (4) blood and air may be aspirated from the pleural space at the time of surgery, (5) the pleural space may be irrigated at the time of surgery, and (6) the patient can usually leave the hospital by the tenth to fifteenth postoperative day unless he has other injuries.

We do not feel that it is necessary to remove these nails, but if it is desirable, this may be accomplished at a later date under local anesthesia as an office procedure. A few of the nails have worked loose over a period of several months. The end of the nail can be felt through the soft tissue. Usually the only symptom produced is the fact that the head of the nail can be felt by the patient.

We have a total of 14 patients treated by some form of internal fixation. All of these have been traumatic fractures except one, which was an esophageal resection where several ribs were divided for more adequate exposure. In 9 of these patients intramedullary Rush nails only were used. Two patients were treated with a combination of intramedullary nail and wire, while in 3 patients wire only was used as a method of fixation. There have been no deaths in this group of 14 patients.



A. *B.*

Fig. 1.—Case 1. *A*, Roentgenogram showing fractures of the right second through eighth ribs, with the lowest four showing double fractures and marked overriding of the posterior fractures. *B*, Postoperative roentgenogram showing expansion of the lung, and reduction with intramedullary nails of fractures of the seventh and eighth ribs.

CASE REPORTS

Case 1.—O. C., a 46-year old white man, was admitted to St. Joseph Hospital on Dec. 18, 1950. He had been cutting timber on December 13, when a tree fell on him. He was given emergency treatment at his local hospital.

Examination on admission showed a deformity of the right lateral chest wall with depression of the fourth through eighth ribs. The respiratory rate was 30. Breath sounds and voice sounds were absent over the entire right chest. Roentgenograms showed multiple fractures of ribs on the right, second through eighth, with the lowest four showing double fractures and marked overriding of the posterior fractures. There was a complete pneumothorax on the right with a small amount of fluid at the base.

On December 19, an intercostal catheter was inserted in the right second intercostal space and attached to a water-seal drainage bottle, with rapid expansion of the lung. On December 22, under general anesthesia, fractures of the right seventh and eighth ribs were reduced and immobilized with Rush intramedullary nails. Fracture of the sixth rib was stabilized with stainless steel wire through drill holes in the ends of the fragments. A moderate amount of bloody fluid was removed from the pleural cavity.

The postoperative course was complicated only by accumulation of pleural fluid, necessitating thoracenteses for removal. On one occasion, streptokinase was injected to liquefy clotted fluid. The patient was dismissed from the hospital on the fifteenth postoperative day (Fig. 1).

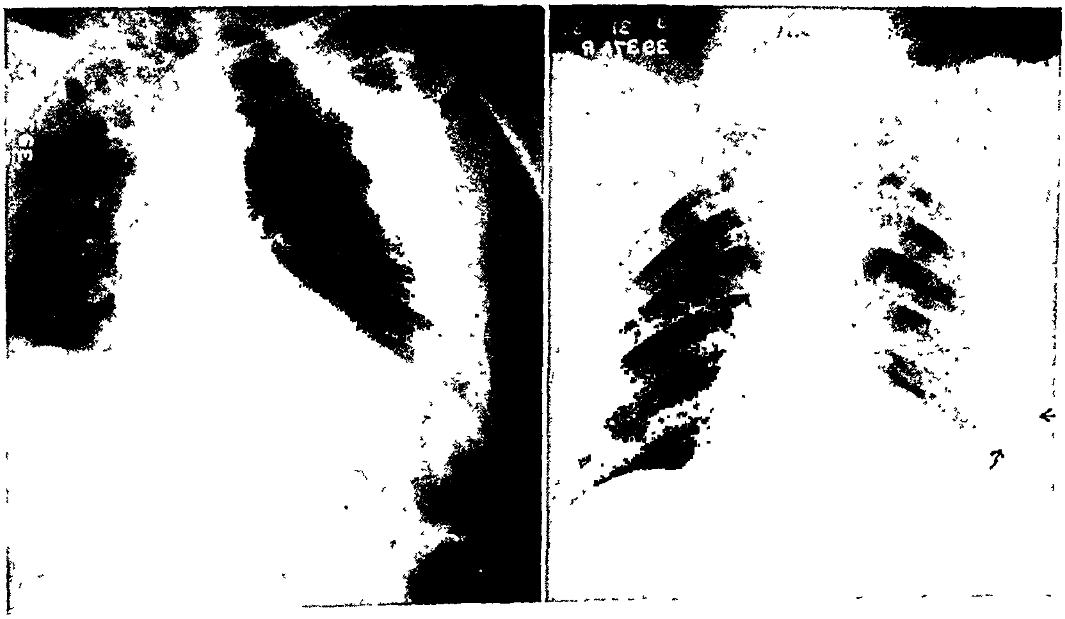
CASE 2.—A. P., a 55-year-old white man, was admitted to St. Joseph Hospital on March 27, 1951. He had been injured in an automobile accident twenty-four hours before admission. He had experienced severe pain in the left chest with difficulty in coughing and breathing since the accident. He was sent to the hospital under oxygen administration in the ambulance. He also gave a history of having had a heart attack five years previously, and subsequently had noted some exertional and nocturnal dyspnea.

Admission examination showed marked mobility of fractured ribs on the left. The patient would not cough because of severe pain. The pulse was 100 to 110. Chest x-ray showed fractures of the left fifth through eleventh ribs, with considerable displacement of the seventh through tenth ribs. There was also moderate amount of fluid in the pleural cavity.

The patient was treated with gastric suction for abdominal distention and sand bags to the injured chest, and was examined by a cardiologist who felt he could tolerate the anesthesia and surgery contemplated.

On March 28, under general anesthesia, the fractured seventh, eighth and ninth ribs were immobilized by Rush nails, and intercostal polyethylene tubes were inserted for postoperative intercostal anesthesia.

Postoperatively, the patient was much more comfortable and the chest wall was quite stable. The recovery was delayed however by development of pneumothorax necessitating the insertion of an intercostal catheter for expansion of the lung. He was dismissed from the hospital on the fifteenth postoperative day (Fig. 2).



A. *B.*

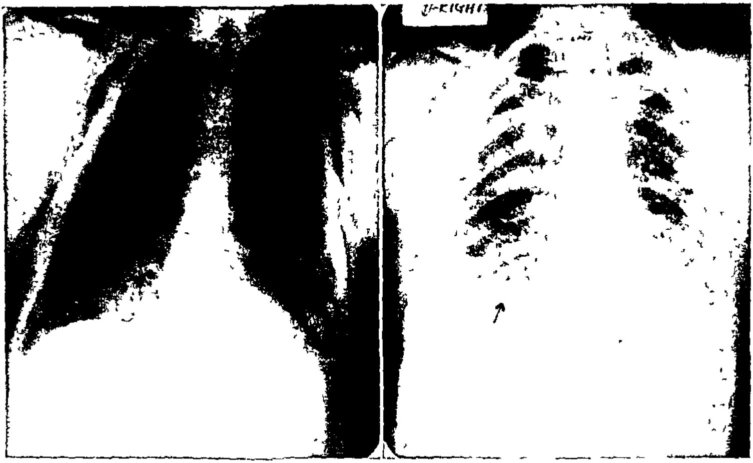
Fig. 2.—Case 2. *A*, Roentgenogram showing fractures of the left fifth through eleventh ribs, with considerable displacement of the seventh through tenth ribs. *B*, Postoperative roentgenogram showing reduction of the fractures by intramedullary nails in the seventh, eighth, and ninth ribs.

CASE 3.—E. B., a 50-year-old white man, was admitted to St. Joseph Hospital on June 2, 1952, a few hours after a tractor had turned over on him.

On admission, the patient was in marked respiratory distress with forced expirations and cyanosis in spite of oxygen administration. There was also an extensive wound of the right face. The blood pressure was 180/70, the pulse 140. There was an obvious deformity of the chest; the sternum was depressed below the medial end of the clavicle on the left, there was a complete separation of ribs from the sternum on the right side, and depressed fracture of the upper anterior ribs on the right. Moderately severe subcutaneous emphysema could be seen and felt over the upper chest and neck. The breath sounds were indistinct and rhonchi were loud over both lower lungs.

Chest x-ray showed bilateral pneumothorax with almost complete collapse of both upper lobes, and marked subcutaneous emphysema of the chest and cervical region. There were fractures of the anterior right first and second ribs with moderate displacement of the first rib.

The patient was taken immediately to the operating room from the x-ray department, and an intercostal catheter was inserted in the anterior second space, right and left, and attached to a water-seal drainage bottle. Air was expressed under pressure from both pleural cavities when an opening was made for the catheter. There was immediate improvement in his breathing and color. A bilateral intercostal nerve block was then done with some relief of pain temporarily. The extensive face wound was débrided and closed under general anesthesia.



A. *B.*

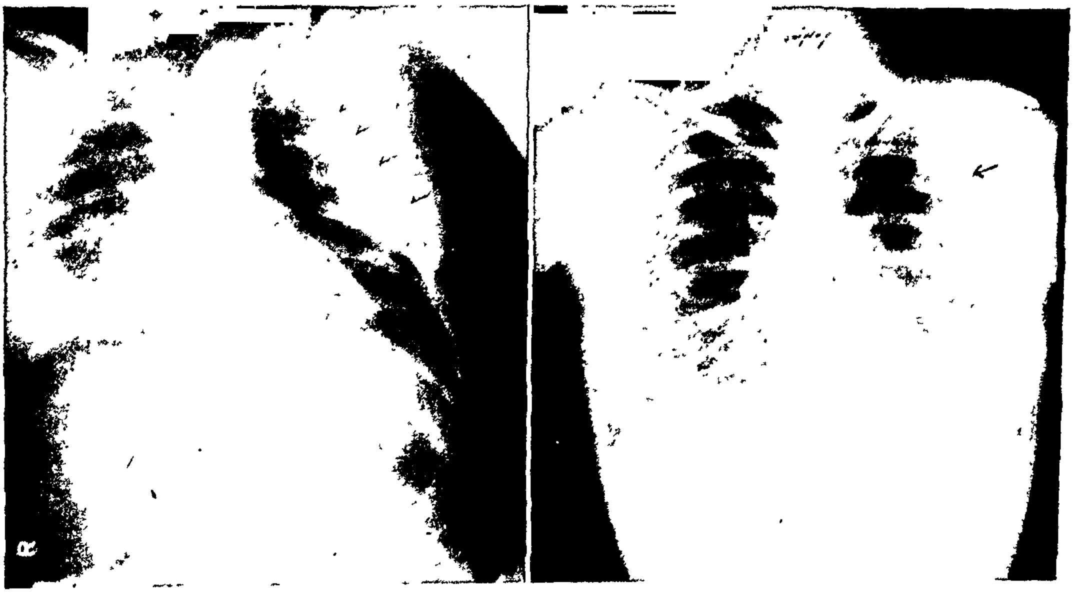
Fig. 3.—Case [illegible] ng bilateral pneumothorax with marked subcutaneous em[illegible] ervical region There are fractures of the anterior righ[illegible] fracture of the sternum at the second rib level, and fra[illegible] ight sternal margin, with complete separation of the ribs fr[illegible] roentgenogram showing the lungs to be expanded. An [illegible] n the fifth rib across the fractured cartilages into the sternum.

The patient continued to have considerable motion at the site of the costochondral fractures along the right sternal margin, and associated pain. On June 3, under local anesthesia, a Rush nail was inserted into the medullary canal of the right fifth rib across the fractured cartilage into the sternum. This stabilized the lower chest, but there was still considerable motion in the upper chest so another incision was made over the right second rib, anteriorly. The sternum was fractured transversely at this level, so would not hold a Rush nail; therefore, the fractures were immobilized with wire and silk sutures.

Postoperative Course.—After admission to the hospital, nasotracheal suction was done every hour. After forty-eight hours it was apparent that secretions were not being adequately evacuated from the tracheobronchial tree, so on June 4, a tracheotomy was done. The lungs remained expanded. There were moderate bronchopleural air leaks for several days but these closed spontaneously. Thoracentesis was done on each side for removal of pleural fluid. The patient was dismissed from the hospital on the eleventh day after admission or the tenth day after stabilization of the chest wall (Fig. 3).

CASE 4.—H. S., a 32-year-old white woman, was admitted to St. Joseph Hospital on July 23, 1954, with history of being injured in an automobile accident three days previously. She had had marked difficulty in breathing and coughing following the injury.

Admission examination showed the patient to be in obvious respiratory distress. She was cyanotic propped up in bed in an oxygen tent. Respirations were rapid and labored with forced expirations. There was a moderate degree of paradoxical motion of the left lower chest wall. There was evidence of multiple fractures of the ribs on the left, and fracture of the left clavicle and right proximal humerus. Pneumothorax had been present on the left side initially, but had been corrected by insertion of an intercostal catheter by her referring physician. Chest x-ray showed multiple left rib fractures, second through ninth, fractured left clavicle and transverse fracture of the surgical neck of the right humerus.



A. B.

Fig. 4.—Case 4. *A*, Roentgenogram showing multiple rib fractures on the left side, second through ninth, and fracture of the left clavicle. *B*, Postoperative roentgenogram showing an intramedullary nail in the fifth rib. The third and sixth ribs are immobilized with stainless steel wire through drill holes in the ends of the fragments.

Shortly after admission of the patient to the hospital, under local anesthesia, the left seventh rib was grasped with a uterine tenaculum in the anterior axillary line and a 5-pound weight attached with rope and pulley. This stabilized the chest wall very well, diminishing the pain and improving the respiratory exchange. The lungs were quite wet, so bronchoscopy was done in bed under local anesthesia with removal of a large quantity of secretions with suction. The morning after admission the lungs were clear and the patient was breathing easily with external traction. On July 25, under intercostal nerve block and local infiltration anesthesia, the left fifth rib fracture was stabilized with an intramedullary Rush nail. Fractures of the left third and sixth ribs were immobilized with stainless steel wire through drill holes in the fragments.

Postoperatively, the chest wall remained stable and the patient had much less pain with coughing. There were no complications. The fractured clavicle and humerus were treated by an orthopedic surgeon. She was dismissed from the hospital on the ninth postoperative day (Fig. 4).

DISCUSSION

A nail or pin of the Rush type seems particularly applicable to multiple rib fractures as it restores the normal contour of the rib and gives good stability to the rib cage when applied to only a few ribs at the center of the deformity The principle of immobilization of fractures by this method has been adequately described elsewhere[8, 9]

Technical considerations—(1) The incision must be adequate to allow the drill and nail to be inserted tangentially to the rib (2) The smallest diameter Rush nail may be too large for very small individuals We have not used the nails in any children, but have encountered this difficulty in a few small adult women We have used wire sutures to approximate the fragments in these individuals (3) In fractures at or near the posterior angle of the rib it is necessary to bend the nail to approximate the contour of the rib, however, the nail should fit tightly and should maintain the normal contour of the rib

SUMMARY

(1) The general management of the patient with multiple rib fractures with instability of the chest wall has been outlined

(2) An operative method of permanent stabilization of the chest wall by intramedullary Rush nails is described

(3) Fourteen patients have been treated by open reduction and fixation of fractured ribs Nine of these have been treated with the Rush nails without other methods of fixation with satisfactory stabilization of the rib cage

Dr O B Murphy and Dr W K Massie, Lexington, Kentucky, have given valuable suggestions regarding use of the Rush intramedullary nails

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SUTURE MATERIAL AND TECHNIQUE FOR BRONCHIAL CLOSURE AND BRONCHIAL ANASTOMOSIS

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BRONCHIAL fistula is not at present a major problem after pulmonary resection. There is practically only one cause of a bronchial fistula, whatever technique for bronchial closure has been used, and that is infection. The decreased incidence of bronchial fistula is therefore due to the antimicrobic therapy. Only once have I observed a bronchial fistula due to a suture being tied so tightly that it cut through the bronchial wall. At reoperation two weeks after the first operation, no signs of infection were observed and healing was obtained by reamputation and suture. A bronchial fistula, at present, is a rare but severe complication. The incidence of suture granulomas is, however, so high that I have made an effort to avoid them.

The suture granulomas are especially harmful in two groups of patients: (1) After bronchial closure in cases of resection for pulmonary tuberculosis. The suture granulomas cause an irritating cough until the sutures are coughed up or are removed by bronchoscopy. The suture granulomas are often found to contain tuberculous tissue and give rise to a positive guinea pig test on sputum or the gastric washing. After removal of the suture granulomas, the guinea pig test will often turn negative. (2) In cases with bronchial anastomosis. Several suture granulomas along the suture line will obstruct the lumen and cause an atelectasis.

Stainless steel sutures were first used as suture material. In the presence of infection, however, bronchial fistulas did occur. The stainless steel sutures often caused tuberculous suture granulomas, and they were difficult to remove by bronchoscopy. We therefore abandoned the use of stainless steel sutures and favored silk sutures on Atraumatic needles. The incidence of suture granulomas did not diminish but the silk sutures were much easier to remove. In cases of bronchial and bronchotracheal anastomosis, the suture granulomas obstructed the lumen and most of the sutures had to be removed by bronchoscopy. Some sutures were coughed up.

In order to avoid suture granulomas, I am now using only chromic catgut on Atraumatic needles (Ethicon 30-day chromic catgut is used, although no difference was encountered with the 20-day chromic catgut). The bronchial fistulas have not increased and the suture granulomas have disappeared. Chromic catgut as suture material for the bronchus has already been used by

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Brunn in 1929 for one-stage lobectomy, by Shenstone and Janes in 1932 for the tourniquet lobectomy, and by Graham in 1933 in his historic, first successful *one-stage pneumonectomy for carcinoma. The fistula that did develop* was not due to the suture material but to the infection. Now we can avoid suture granulomas by going back to catgut as suture material for the bronchus

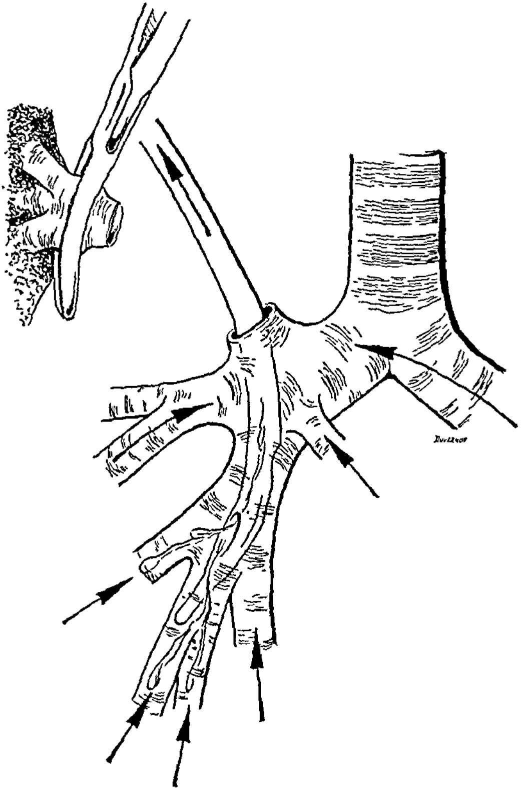

Fig 1.—A clamp is placed on the bronchus peripheral to the division, but not on the central stump The bronchial tree is aspirated before the bronchus is closed

METHODS

I. Earlier we used the invagination technique for bronchial closure described by Crafoord. Excellent results were obtained by this method even before the introduction of antimicrobic therapy. The invagination is easy to perform on a soft bronchus, especially after a pneumonectomy. A pedicled pleural flap was sutured over the bronchus.

II. Isolated stainless steel sutures and later silk sutures were used for bronchial closure in a group of cases for comparison with the invagination technique. A pedicled pleural flap was sutured around the bronchus.

III and IV. Catgut sutures on Atraumatic needles were used as the suture material. In Group III, fine Deknatel silk sutures were placed between the

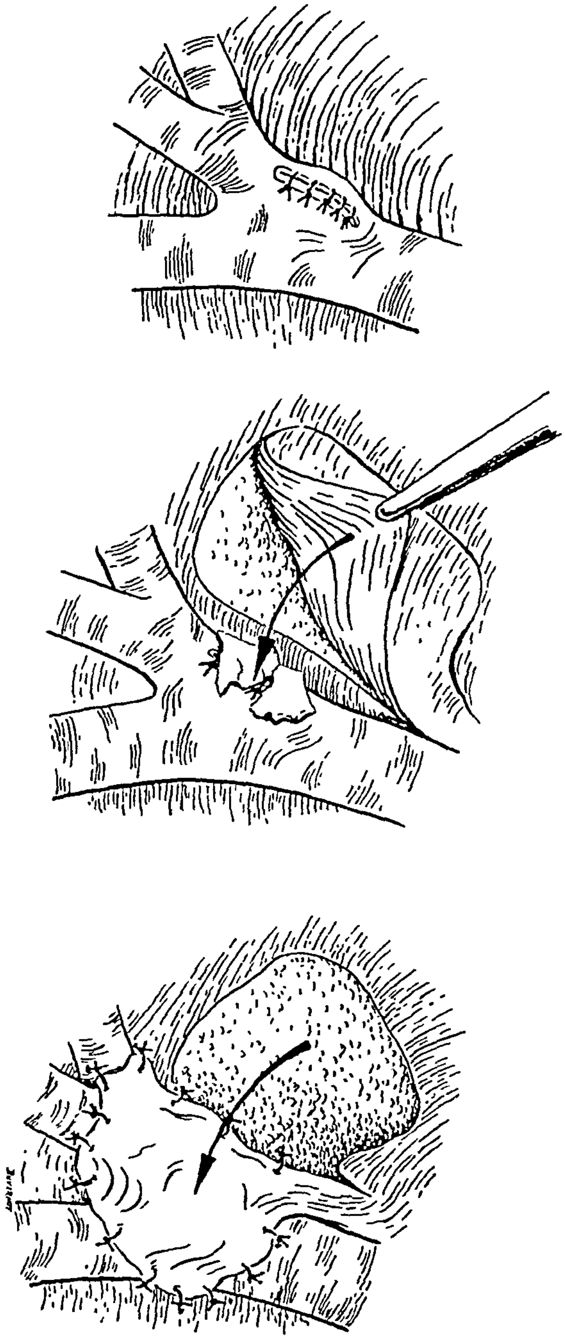

Fig. 2.—The bronchus is closed with one row of isolated terminal catgut sutures. Streptomycin crystals are placed under a pedicled pleural flap sutured around the bronchial stump.

catgut sutures, care being taken to place the silk sutures extramucosal when possible In Group IV, only catgut sutures were used The bronchial stump was always covered with a pedicled pleural flap The present technique for bronchial closure is as follows

1 In order to avoid trauma to the bronchial stump, a central clamp is never used and the bronchus is treated open Any accumulated secretion is sucked out first The prone position is used in cases with tuberculosis, see Fig 1

2 To avoid suture granulomas, catgut on Atraumatic needles is used For a segmental bronchus, No 4 0 or 3 0 catgut is used, for a lobar bronchus No 3 0 and for a pneumonectomy No 3 0 or 2 0 is used One row of isolated terminal sutures is used They should not be tied too tightly or they may cut through

3 In order to diminish the danger of infection with bronchial fistula, a high local concentration of streptomycin is obtained by placing streptomycin crystals under the pedicled pleural flap which is sutured on the bronchus, see Fig 2

RESULTS

In order to evaluate the different techniques for bronchial closure only cases of pneumonectomies and lobectomies for pulmonary tuberculosis have been analyzed The incidence of fistulas in cases of segmental resection is higher, but these fistulas are often due to leakage from the resection area As it may be difficult to prove if a fistula is localized in the segmental bronchus or in the resection area, cases with segmental resection are excluded from this analysis

Pneumonectomies—The findings from 146 pneumonectomies are shown in Table I There are altogether 3 cases of bronchial fistula (2 1 per cent), 2 were caused by a tuberculous infection, the third was secondary to a staphylococcal empyema The 2 cases with tuberculous infection were reoperated upon, the bronchus closed with stainless steel sutures, and the thoracoplasty enlarged In both cases, the bronchus reopened after a few days and the patients died later on Invagination will not prevent a bronchial fistula in the presence of infection

TABLE I THE COMPLICATIONS OF BRONCHIAL CLOSURE AFTER PNEUMONECTOMIES FOR PULMONARY TUBERCULOSIS

	TECHNIQUE OF BRONCHIAL CLOSURE	TOTAL NUMBER OF CASES		BRONCHIAL FISTULA	SUTURE GRANULOMA
I	Invagination	65		1	4
II	Isolated silk or stainless steel sutures	42		1	8
III	*Catgut + silk*	*18*	39	*0*	*0*
IV	Catgut	21		1	0
	TOTAL	146		3	12

Twelve of the 107 cases in which the bronchus was closed with silk or stainless steel sutures had to have the sutures removed from the bronchial stump by bronchoscopy. One of these patients had to have 5 bronchoscopies performed for removal of sutures causing granulomas. (This incidence of suture granuloma may be too low as only patients with a long-standing irritating cough were bronchoscoped.)

Five patients reported that they coughed up sutures. Naturally, more patients have coughed up sutures without noticing or reporting it. No suture granulomas have been found in the cases with the bronchus closed with catgut.

Lobectomies.—The findings in 230 cases of lobectomy for pulmonary tuberculosis are summarized in Table II. The invagination technique was used in only 4 cases. There is a danger in invaginating the bronchus too much of obstructing the proximal bronchus. As nothing is to be gained by the invagination technique, the simple closure described is preferred.

TABLE II. THE COMPLICATIONS OF BRONCHIAL CLOSURE AFTER LOBECTOMIES FOR PULMONARY TUBERCULOSIS

TECHNIQUE OF BRONCHIAL CLOSURE	TOTAL NUMBER OF CASES	BRONCHIAL FISTULA	SUTURE GRANULOMA
I. Invagination	4	0	0
II. Isolated silk or stainless steel sutures	113	3	17
III. Catgut + silk	55 } 113	0	0
IV. Catgut	58	0	0
TOTAL	230	3	17

Fistula: There were 3 cases complicated with bronchial fistula, 1 due to a tuberculous infection, 1 followed an infection with *Staphylococcus aureus* in a plastic plomb placed extrapleurally after the lobectomy. The third bronchial fistula followed a lobectomy in which a staphylococcal empyema was opened during operation. All 3 cases were reoperated on, the bronchus closed with stainless steel sutures or silk but the bronchus reopened in all 3 cases after a few days. Two patients died, 1 (with the infected plomb) survived after a wide excision of the chest wall (Schede thoracoplasty).

Sutures had to be removed in 17 of 117 cases having the bronchus closed with nonabsorbable suture material. This incidence of suture granuloma may be too low as only patients with an irritating cough were bronchoscoped. The suture granuloma may contain tuberculous tissue and be a serious complication. In one case a reoperation was necessary (see Case 1).

CASE REPORT

CASE 1. A 28-year-old woman had the basal segments of the right lower lobe removed in 1950 for a tuberculous cavity. The bronchus was closed by four isolated stainless steel sutures and one running suture of fine linen. The stump was covered by a pedicled pleural flap. During the following four years, the patient had eight bronchoscopies performed for treatment of tuberculous suture granulomas. All of the stainless steel sutures could not be removed through the bronchoscope. In 1953, the patient developed a tuberculous cavity in the remaining superior segment of the right lower lobe. In June, 1954, a resection of this superior segment right lower lobe was performed as well as a reamputation of the lower lobe bronchus above the old suture line Inspection of this suture line showed a stainless steel suture in the center of necrotic mucosa The stainless steel suture was surrounded by granulation tissue which proved to be tuberculous at the microscopic investigation

There were 7 cases with bronchotracheal or bronchial anastomosis In 3 cases, the anastomosis was performed with silk sutures All 3 patients had to have the sutures removed by bronchoscopy Suture granulomas around the suture line caused partial obstruction and 1 patient had to have six bronchoscopies performed for removal of all silk sutures before healing was obtained In 4 cases, the bronchial or bronchotracheal anastomosis was performed with chromic catgut sutures Bronchoscopic control after one to two months revealed smooth healing of the suture line with no suture granulomas

SUMMARY

Bronchial fistula is a rare complication practically always due to infection The incidence of bronchial fistula does not increase if catgut is used as suture material

The use of nonabsorbable suture material has caused suture granulomas in a significant number of cases In cases of bronchial or bronchotracheal anastomosis, the suture granulomas may obstruct the lumen In cases of resection for pulmonary tuberculosis, tuberculous granulations may be found around the suture The use of catgut will prevent the formation of suture granulomas

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INTRACARDIAC ANGIOGRAPHY: CONTROLLED INSTANTANEOUS INTRA-ATRIAL RELEASE OF CONTRAST MATERIAL IN MAN

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SINCE the demonstration of the practical applications of angiocardiography by Robb and Steinberg in 1938,[1] numerous modifications have been set forth. However, little alteration of their basic method has occurred. Technical advances have followed two courses: (1) improving the technique and increasing the frequency of serial radiography, and (2) achieving adequate concentration and localization of contrast substances.

1. Biplanar exposures at a rate of ten to twelve per second[2] and cinefluorography[3] provide excellent serial visualization of the flow of contrast material through the heart and great vessels. Unfortunately, this requires complex expensive equipment. Generally, rapid cassette changers,[4] or roll film magazines[5] are adequate for most clinical work. As a matter of fact, single or timed multiple exposures with existing x-ray equipment may prove satisfactory, although such techniques are probably no longer justified.

2. Adequate concentration of the contrast material to permit visualization can be produced only by very rapid injection of the viscous, highly concentrated contrast substance into a suitable vein.[1] To prevent dilution of the dye as it enters via the systemic veins into the heart, large-bore intracardiac catheters have been inserted via the external jugular vein.[4] "Selective" angiograms can be obtained by means of a No. 9 cardiac catheter with the contrast material injected under great pressure.[7] Direct heart puncture allows injection of the contrast substance into one of the ventricles[8] or into the left auricle.[9] Artificial reduction of intrathoracic circulation as an aid in angiocardiography has recently been proposed.[10]

In our experience, adequate angiocardiographic visualization can be obtained in most children using the standard technique of injection of the contrast material (usually 70 per cent Diodrast) into a suitable arm vein. The roll film magazine provides exposures at one-half to one second intervals. However, satisfactory visualization in adults is limited by the rapid dilution of the injected substance. Rapid intravenous injection of 70 per cent Diodrast in volumes of 40 to 50 c.c. is hard to achieve. Particularly in patients with

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cardiac enlargement, adult angiocardiograms have been of poor quality. viously, a more nearly ideal method requires the liberation of a bolus of centrated contrast material within the heart.

Because of obvious difficulties and dangers associated with such procedu as direct cardiac puncture, various other possibilities have been explored this laboratory. This communication is a preliminary report of our earl experience with a method which provides controlled instantaneous release o large volumes of contrast material within the right atrium. This method has proved to be safe and practical for most clinical applications.

DEVELOPMENT OF TECHNIQUE

A special balloon-tipped catheter had been used to produce unilateral pulmonary artery occlusion[11] in more than 60 patients undergoing hemodynamic studies. No significant untoward effects had occurred. Despite the rather complex structure of the catheter, thrombo-embolic complications have been of no consequence. In the course of five of these studies, inflation with 8 to 20 c.c. of 15 per cent Diodrast inadvertently caused rupture of the rubber cuff, with sudden liberation of the contrast material as seen by fluoroscopy. In no case was this rupture attended by any subjective symptoms. The obvious application of this observation to angiography then presented itself.

Various methods for sudden liberation of the contained contrast material from the balloon were explored. When a rubber balloon was tied over the end of a cardiac catheter, overinflation, of course, produced rupture; but prediction of the volume necessary or time of rupture was impossible. Also, the danger of fragmentation of the rubber with embolization appeared prohibitive. Methods for release of the balloon by slipknots, weakened seams, and electrocautery were also attempted and ultimately rejected. Finally, a model was constructed which in preliminary studies appears satisfactory.

METHOD

At this writing, continuous modification of the special catheter is under way. Following each study, the construction of the catheter has been altered. Fig. 1 shows an over-all view of the catheter, with a close-up of the tip, of he parent model, which was constructed from a standard double lumen cardiac atheter. Details are given in the legend for Fig. 1.

This technique has been applied only in adults or large children. The ocedure is carried out as in ordinary cardiac catheterization, in the fasting e, under mild sedation (0.1 Gm. secobarbital). Under local anesthesia a e median vein in either arm is isolated and, with the balloon completely ted, the tip of the catheter inserted. Heparin, 25 to 50 mg., may be given revent possible fibrin deposition. Under fluoroscopic and electrocardio- ic control, the catheter is advanced until the tip has passed into the atrium and just into the inferior vena cava. A small volume of contrast al (5 to 10 c.c.) is then injected to observe the position of the balloon, hould be in mid-atrium. The patient is then positioned before the d the desired amount of contrast material (40 to 50 cent Diodrast) is injected as rapidly as possible (usually in 60 seconds). One second after x-ray exposures at one-half to one second intervals are begun, a sudden pull is exerted on the wire. This pulls down the cuff holding the proximal end of the balloon, resulting in sudden liberation of the contained solution. The catheter is withdrawn as soon as the exposures are completed.

RESULTS

Satisfactory x-ray visualization has been obtained in the first 5 patients studied. The illustration herein presented is from the fifth patient studied and represents the best result so far achieved. This patient was an eighteen-year-old

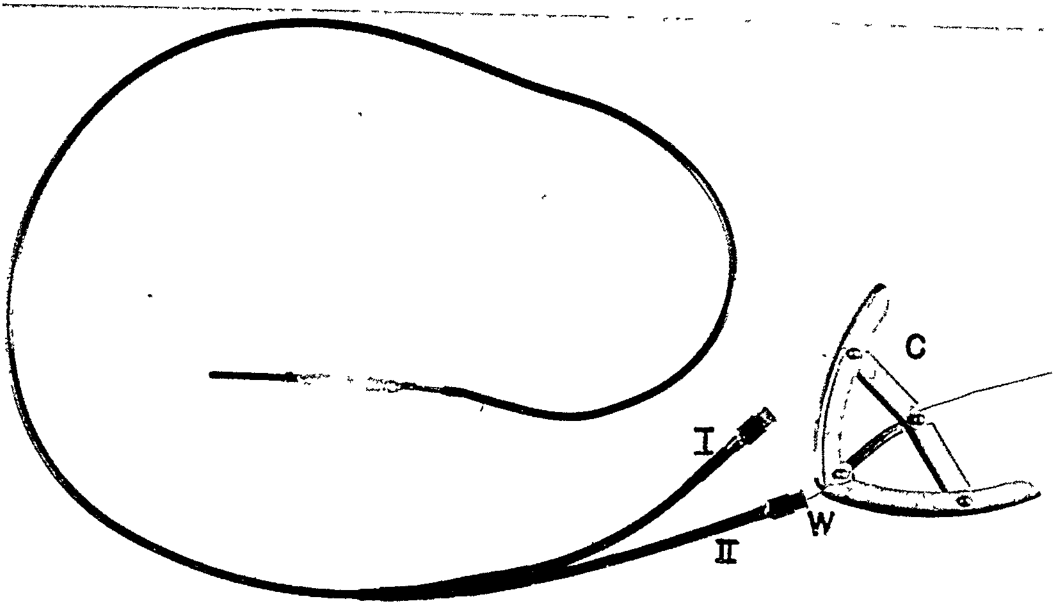

Fig. 1*A*.—Balloon-tipped catheter for controlled instantaneous release of contrast material in right atrium. The upper fitting, *I*, is for injection of contrast material via that lumen into the balloon at the tip. From the lower fitting, *II*, emerges a fine stainless steel wire, *W*, extending down this lumen. Pressure on the spring clamp, *C*, causes the wire to pull down the cuff which had secured the proximal end of the balloon.

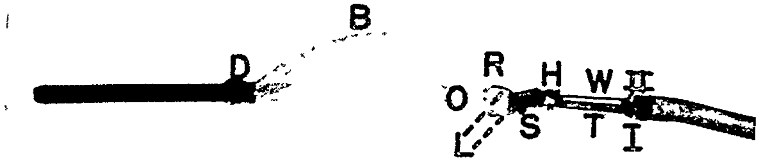

Fig. 1*B*.—Close-up of tip of catheter, actual size. *B*, latex balloon securely held by tight rubber cuff, *R*. Balloon is inflated via lumen *I* through hollow stainless steel tubing, *T*, ending in single-lumen catheter which is blocked off at its tip; an opening at its side, at *O*, inflates the balloon. Two fine silk ligatures, *L*, tied proximal to a shoulder, *S*, on *T* are drawn under cuff, *R*, and then back over to be tied to the end of the wire, *W*, which runs parallel to *T*, and ends in a ring, *H*, just proximal to shoulder, *S*.

After the balloon is inflated by the desired volume, sudden tension on the wire pulls down the two silk ligatures causing cuff, *R*, to roll back off the proximal end of the balloon, so that the contained material is suddenly liberated.

female with severe limitation from infancy, due to congenital heart disease. A clinical diagnosis of pulmonic stenosis was made. At cardiac catheterization, a classical pulmonary artery–right ventricular pressure gradient of severe pulmonic stenosis was demonstrated (Fig. 2). The abrupt transition from the low pulmonary artery pressure to the very high right ventricular pressure established the fact that the stenosis was valvular (rather than infundibular).

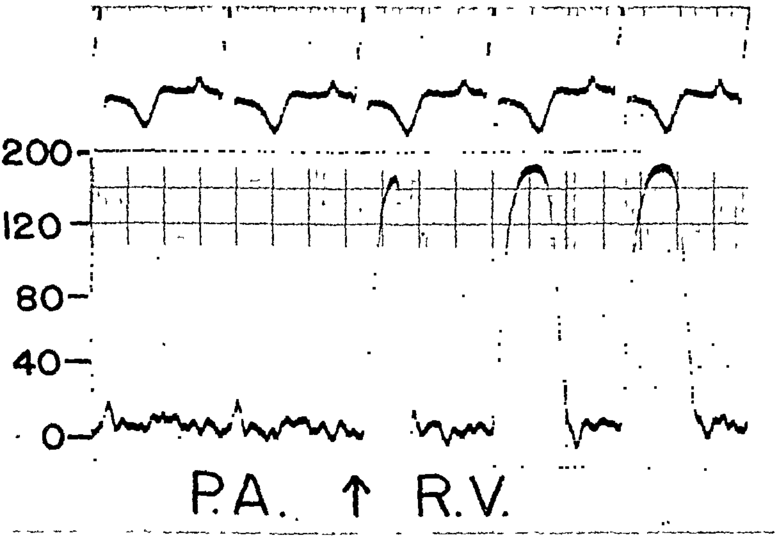

Fig 2.—Isolated valvular pulmonic stenosis Pressure tracings as catheter tip was slowly withdrawn from pulmonary artery (PA) to right ventricle (RV) show abrupt transition at the pulmonic valve (arrow) from low to very high pressure (Electrocardiogram, Lead II, recorded simultaneously.)

The illustrations in Fig. 3 were *selected from a series obtained* during intracardiac angiography performed on this patient using the previously described technique. Fig. 3, *A* shows the inflated balloon in place in the right atrium just before release of the *contrast material*. In Fig. 3, *B*, one-half second after release, excellent visualization of the right ventricle is obtained. Fig. 3, *C* and *D* demonstrate the pulmonic valve during diastole and systole. The valve appears to be displaced somewhat upward and the outflow tract of the right ventricle appears narrowed.

Operation was performed by Dr. Claude S. Beck. The diagnosis and the position of the stenotic valve *were confirmed*; the very thick-walled outflow tract of the right ventricle was demonstrated Section of the valve was followed by an excellent pressure response Significant clinical improvement has resulted.

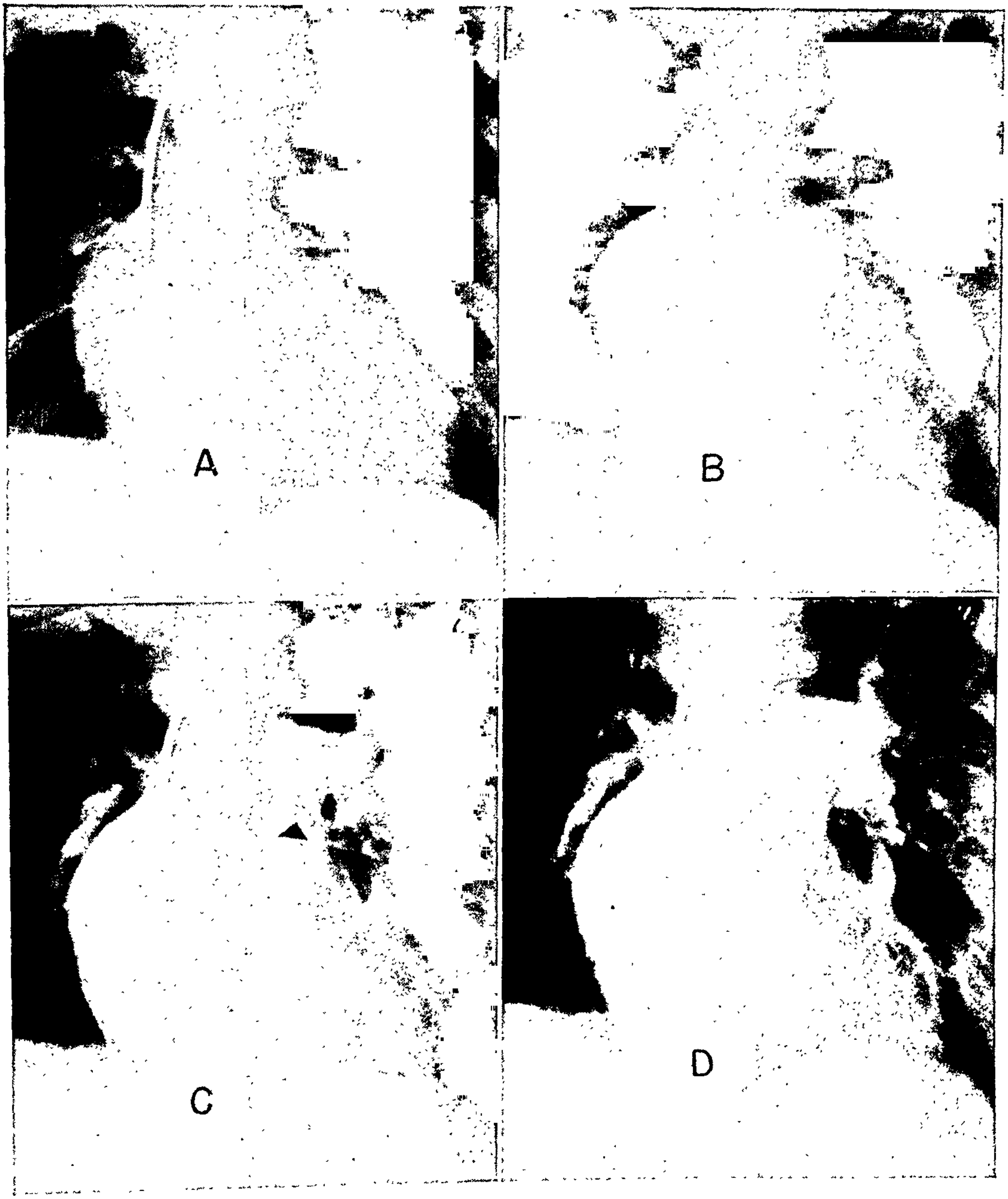

Fig. 3.—Intracardiac angiography by controlled instantaneous release of 40 c.c. of 70 per cent Diodrast in right atrium. Eighteen-year-old girl with isolated valvular pulmonic stenosis. Anteroposterior projection.

A, Balloon inflated with 40 c.c. of Diodrast in right atrium, just before relase.

B, One-half second after release. Note reflux up superior vena cava. The internal architecture of the right ventricle is well shown. The dye is just about to enter the pulmonary artery.

C, One-half second later, during diastole. Arrow is just at pulmonic valve. Architecture of valve demonstrated, and tiny "string sign" of dye.

D, One-half second later, during systole. Outflow tract of right ventricle narrower than *C* with larger opening in pulmonic valve.

Similar intracardiac angiograms have been performed in patients with the following: Ebstein's disease, tricuspid stenosis (postoperative), atrial septal defect, and mitral insufficiency.

COMMENT

In view of the inherent danger of occlusion of one or more of the orifices of the right atrium, it was considered advisable to carry out the first studies in patients with enlarged right atria. However, since inflation of the balloon and release can be carried out within one minute, any possible ball-valve effect can only be temporary.

In the first 5 patients in whom the complete procedure was carried out, the over-all reaction to sudden liberation of the dye appeared less severe than is usually observed with standard injection. Presumably, although a higher instantaneous concentration of dye perfuses the cerebral and coronary vessels, its rapid dispersal would make it less dangerous than perfusion of the vessel with a somewhat lower concentration but for a relatively much longer period of time.

Although fibrin particles are occasionally found on the catheter after removal, in the absence of a significant right-to-left shunt this appears to be of no consequence.

It appears that this method of instantaneous release of contrast material in the right atrium allows for more accurate timing of flow through the various cardiac chambers. Furthermore, the presence of a more concentrated "bolus" gives a higher concentration of contrast material for a longer period of time. The undesirable factor of continued flow into the right atrium from the superior vena cava is obviated. Superimposition of contrast material in various chambers is reduced.

Since the substance within the balloon is relatively noncompressible, sudden release does not greatly alter intracardiac flow pressure relationships such as would occur with introduction of the material under great pressure via an intracardiac needle or catheter.

General anesthesia, as required for most of the other special methods, has not been necessary, so that maximum patient cooperation can be obtained. Positioning of the patient is particularly easy, more so even than for ordinary angiocardiography. Once the catheter position is secured, the patient's arm need not be held elevated to obtain rapid injection of the dye. Injection into the catheter can be done in any comfortable position.

Where no special serial radiography apparatus is available, this method permits more accurate timing of the selected exposures. Unfortunately, however, repeat studies can only be done following removal of the catheter, reassembly of the balloon and release mechanism, and reinsertion of the catheter.

Since none of the highly concentrated contrast material comes into contact with the systemic vein used for insertion of the catheter, there is less likelihood of severe thrombophlebitis, although the catheter itself is somewhat irritating. There is no evidence that the sudden liberation of the material inside the heart produces endocardial irritation.

Further studies are now being performed. Simultaneous recordings of intracardiac pressures, arterial pressure, and electrocardiogram are being carried out during inflation and release of the balloon. An apparatus has been designed to correlate release and x-ray exposures with phases of the cardiac cycle.

SUMMARY

By means of a specially designed balloon-tipped cardiac catheter, a large volume of contrast material may be released instantaneously in the right atrium. This appears to be a safe and effective method for achieving adequate visualization for angiocardiographic purposes.

In the first 5 patients studied, the rapid liberation of the material produced no untoward effects. Studies in a patient with congenital pulmonic stenosis are presented. Excellent visualization of the right ventricle and stenotic pulmonic valve are demonstrated.

Further studies are now being conducted to determine the hemodynamic and electrocardiographic effects of this procedure and also to develop a catheter suitable for mass production.

I wish to acknowledge the technical assistance of the following: Bernard L. Charms, M.D., John Elder, M.D., Melvyn Reydman, M.D., Robert Newman, M.D., Mary Ellen Beck, Howard Siegel, Mary Rizika, Delores Fader, and Lou Vacha—all of whom contributed to the development of the method.

ADDENDUM

Since this report was submitted, a single lumen catheter with a simplified release mechanism has been devised, allowing more rapid injection and release of contrast material. More than 25 studies have been carried out, particularly in patients with rheumatic heart disease being considered for operation. Excellent results have been achieved (to be reported subsequently) without untoward effects.

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MELANOCARCINOMA OF THE ESOPHAGUS

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INTRODUCTION

SINCE Baur's first reported case of malignant melanoma of the esophagus in 1906,[1] a total of 15 have appeared in the world literature [2-16] The seventeenth case, which is described below, prompted us to review the available material in an attempt to resolve it into a concrete clinical and pathologic picture that might aid in the future diagnosis and treatment

CASE REPORT

F M, a 61 year old Negro woman, was first admitted to the North Carolina Memorial Hospital on July 15, 1954, with the chief complaint of "difficulty in swallowing" solid food of about four months' duration She experienced the sensation of food "getting stuck down deep" accompanied by mild epigastric burning and interscapular pain Liquids in small quantities passed freely, and there was no history of cough vomiting, sialorrhea, or hoarseness She had lost about 20 pounds since the onset of her illness Her general health had always been excellent, and the review of systems was noncontributory

At the time of physical examination, the patient appeared as a well developed, moderately well nourished, elderly Negro woman in no acute distress The temperature was 99° F, blood pressure 130/80, and pulse 80 A critical examination of each of the systems was essentially negative

Routine laboratory studies that included a complete blood count, urinalysis, blood urea nitrogen, carbon dioxide capacity, serum chlorides, sodium and potassium, total proteins, and albumin were all within normal limits An electrocardiogram was not remarkable

A barium swallow outlined the esophagus in its entirety An irregular, lobulated filling defect was described at the junction of the middle and distal thirds (Figs 1 and 2) The radiologic impression was fungating carcinoma of the esophagus

On the second hospital day, a bronchoscopy and an esophagoscopy were performed The bronchoscopy revealed no abnormalities, but a large, polypoid, dark bluish mass was encountered in the esophagus at the level described by the radiologist A biopsy was taken The histologic sections revealed a normal mucosa, submucosal infiltration by pleomorphic, anaplastic appearing cells containing varying sized, brownish pigmented granules that were nonreactive to iron stains The pathologic diagnosis was malignant melanoma The skin, eyes anus, rectum, and genitalia were carefully re examined for a possible primary site but none was found Urinalysis for melanin was negative

On the fifth hospital day, an esophagectomy, esophagogastrostomy, and pyloroplasty were carried out through a left thoracotomy incision The esophagus was not fixed to the adjacent mediastinal structures Abdominal exploration revealed no gross liver metastases but pigmented lymph nodes were found near the celiac axis and along the distal third of the esophagus The patient tolerated the procedure well

Pathologic examination of the surgical specimen revealed a 14 cm segment of esophagus with regional lymph nodes attached (Fig 3) Five centimeters from the proximal end was a

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single, deeply pigmented, firm, pedunculated tumor mass measuring 4 by 2.5 by 1 cm. Its pedicle was broad, measuring approximately 2 cm. across and 1 cm. in length. The surface of the lesion was irregularly lobulated and covered in part by dull gray epithelium. Shallow superficial areas of ulceration were common and occasionally confluent. On section the cut surface was dark brown. It showed no gross evidence of necrosis, hemorrhage, or extension into the underlying muscle. About the point of pedicle attachment to the wall, there were numerous, raised, purplish, "daughter" lesions that measured up to 1 cm. in diameter. The mucosa of the distal 7 cm. was gray and unremarkable. Adjacent to the tumor, it was diffusely purple in color. All of the attached regional lymph nodes were found to be slightly enlarged and deeply pigmented.

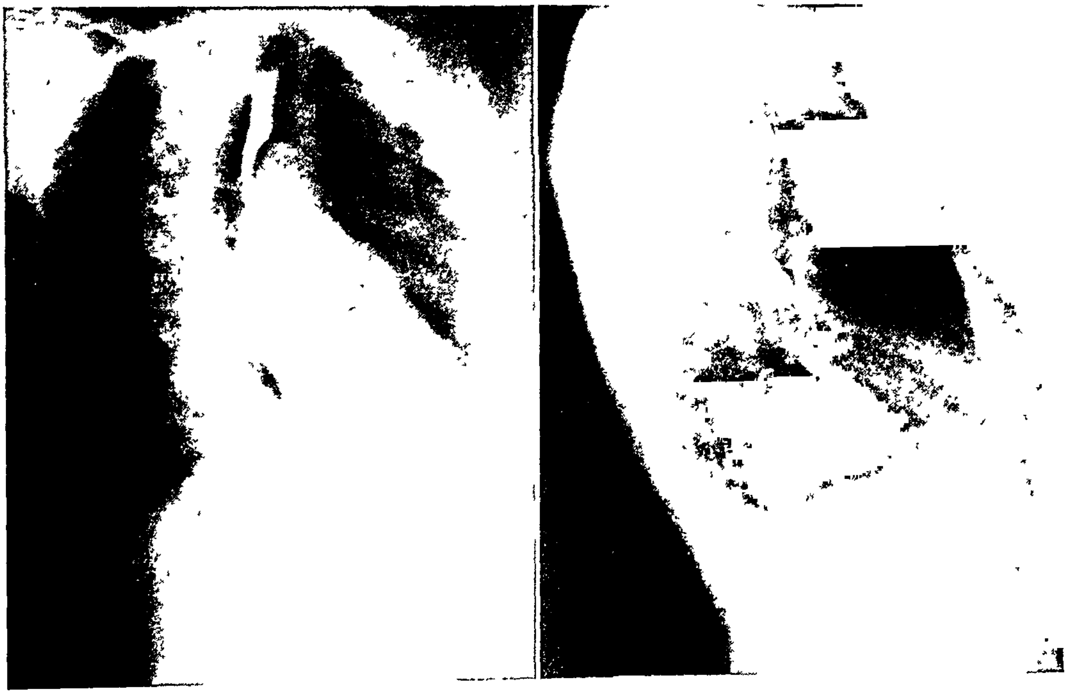

Fig. 1. Fig. 2.

Figs. 1 and 2.—Barium contrast studies of esophagus showing filling defect near junction of middle and lower thirds.

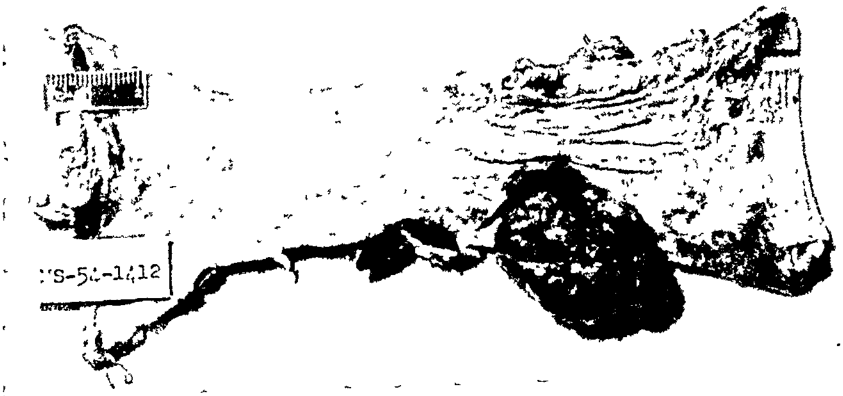

Fig. 3.—Segment of esophagus removed at operation containing polypiform melanocarcinoma with marked pigmentation of the distal regional lymph nodes and adjacent proximal mucosa.

Microscopic examination of numerous sections revealed essentially the same picture. The neoplasm was exceedingly cellular and showed marked anisocytosis, anisonucleosis, indistinct cell borders, frequent mitotic figures, and excessive extra- and intracellular brown pigment (Fig. 4).

The overlying epithelium was compressed, and a striking adjacent junctional change was present. Irregularly replacing the basal layer and extending slightly into the submucosa was a loose network of altered epithelial cells. These showed a wide range of variation in nuclear size, shape, and staining qualities, prominent nucleoli, markedly reduced cytoplasm, and both intra- and extracellular deposits of dark-brown pigment. A representative area is shown in Fig. 5.

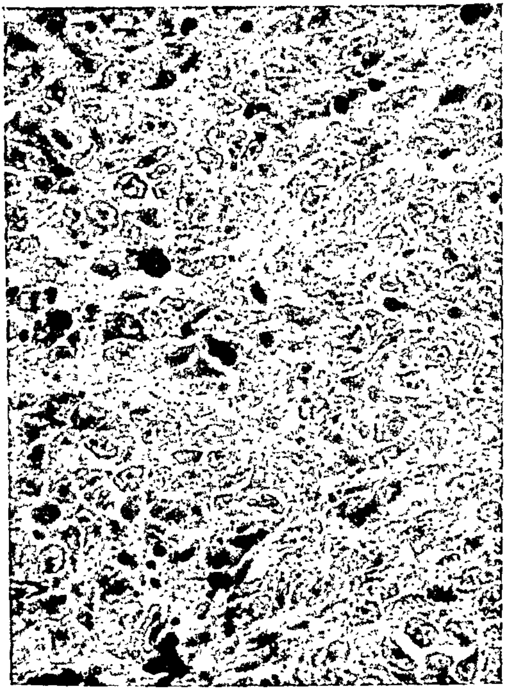

Fig. 4.—Photomicrograph of melanocarcinoma showing a wide range of nuclear variation and intra- and extracellular melanin formation (×430).

The tumor had extended laterally for varying distances into the submucosa and was found within lymphatic vessels. Examination of lymph node sections showed their deep pigmentation to be due to large quantities of melanin pigment within the reticuloendothelial cells and monocytic macrophages. One small focus of metastatic melanocarcinoma was identified. Stains for iron were negative, and the pigment was found to turn black in silver preparations. The final pathologic diagnosis was: melanocarcinoma of the esophagus with adjacent junctional epithelial change and metastases to regional lymph nodes.

The immediate postoperative course was unremarkable except for an episode of auricular fibrillation that responded well to digitoxin.

Over the past fourteen months she has been seen periodically in the Outpatient Clinic. Anorexia, dysphagia, and weight loss have persisted, although two barium swallows have outlined a patent but slightly constricted operative site. Esophagoscopy has failed to demonstrate local recurrence. X-ray examinations of the chest and skeletal system have been negative for evidence of metastases.

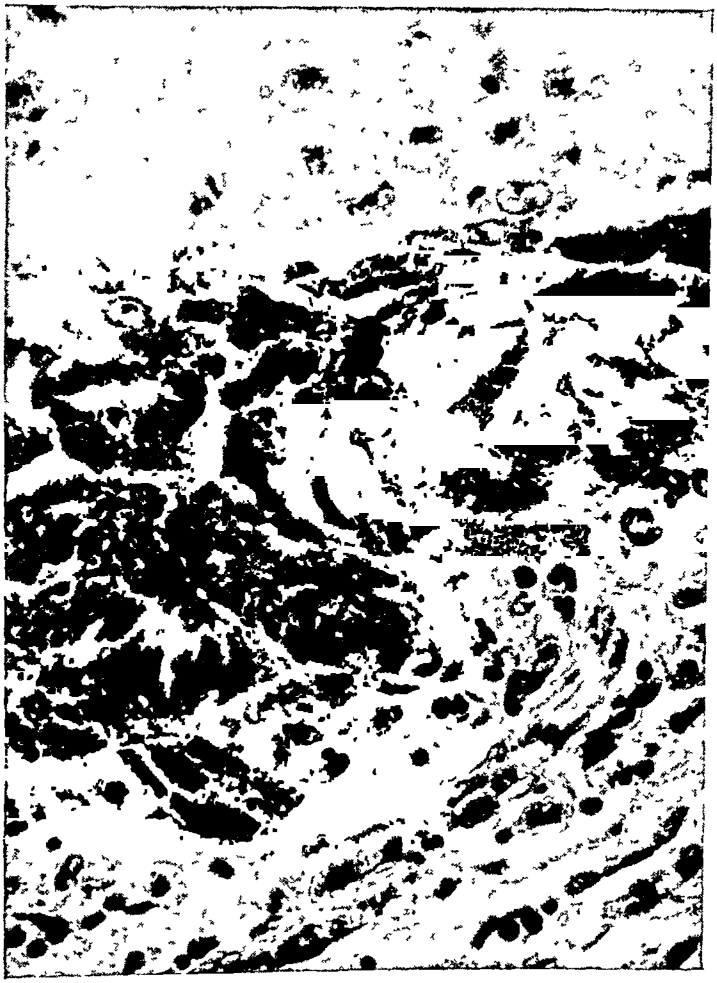

Fig 5.—Photomicrograph of junctional change adjacent to melanocarcinoma The cells of the basal layers of the mucosa have lost their polarity, become detached, and contain large quantities of melanin pigment (×430).

CLINICAL FINDINGS

A summary of the clinical data from the 17 reported cases is given in Table I. The patients' ages ranged from 40 to 71 years with an average of 60 years. The sex distribution was 11 males and 6 females with a ratio of 1.8 to 1. All of the patients were white except Sirsat's, who was a native of India, and the one described here, who was a Negro woman. The duration of symptoms extended from 5 to 52 weeks with an average of 21.1 weeks. We have omitted from these last computations Joliat's[2] and Robertson's[14] cases. In Joliat's report, the symptoms were described as being present for ten years, which seems justifiably open to question. The reported duration in Robertson's case was one and one half years, but the clinical picture was somewhat altered by an associated adenocarcinoma of the colon and rectum.

The clinical picture was typical of a progressively obstructing lesion of the esophagus. An analysis of the symptomatology is given below.

Dysphagia was the most frequent complaint and resulted from the obstruction. This was always partial. It was associated with a sense of discomfort that included fullness of the epigastrium, substernal pressure, precordial burning, weight in the "pit of the stomach," and postprandial bloating. Pain caused by the act of swallowing and by the passage of food was not uncommon. It was most frequently located behind the sternum and occasionally radiated through to the back.

Weight loss was present in every case. It ranged from 3 to 45 pounds and was directly proportional to the duration of symptoms. Weakness commonly accompanied weight loss and became quite marked as clinical deterioration reflected the progressive growth of the tumor. Excessive sialorrhea was an interesting and frequent complaint, and it was not always associated with the intake of food or drink.

A secondary group of complaints consisted of cough, hoarseness, and orthopnea. As will be seen under the descriptions of the gross and microscopic pathology, these cannot readily be explained.

Physical signs of the disease were conspicuously absent. One patient presented a palpable left subclavian lymph node that subsequently proved to be metastatic melanoma.[8] In 2 others, melena was the only significant sign.

Laboratory findings were equally infrequent. Routine peripheral blood studies, urinalysis, and blood chemistries were within normal limits. Occult blood was present in the stools of 2 patients.

In every case, the general nature of the lesion was suspected from the history. Roentgenologic examinations, using barium as the contrast medium, were carried out in 13 patients. A filling defect was found in 11, and in 2 patients the lesion was completely overlooked. In one instance, the defect was found only after the third upper gastrointestinal series, and in another it was interpreted as a benign tumor.

A specific diagnosis was made by tissue examination in all instances. This was obtained by esophagoscopy and biopsy in 11 cases, following operation in 2 cases, and only at necropsy in 4 cases.

The therapy was symptomatic in 6 patients, radiation to the metastases in 1, and by surgical resection in 10. In Sirsat's case,[10] the patient signed himself out of the hospital and died at home two years later without further known treatment.

The reported over-all survival time varied from 3 days to 2 years with an average of 6.98 months. The given survival time for those patients whose lesions were removed surgically ranged from 3 days to 15 months with an average of 7.4 months. At the time the respective reports were made, however, 1 patient on symptomatic therapy was still alive 1 year after the diagnosis was made.

Table I. Summary of Clinical Data of the Seventeen Reported Cases of Melanocarcinoma of the Esophagus

NUMBER	AUTHOR AND DATE	AGE	SEX	RACE	DURATION OF SYMPTOMS (WEEKS)	SITE OF LESION	THERAPY	SURVIVAL TIME		NOTE
								FROM ONSET OF SYMPTOMS	POST-OPERATIVE	
1.	Baur—1906	69	M	W	30	Upper ⅓	Symptomatic	30 weeks		Died shortly after admission to hospital; autopsy
2.	Joliat—1907	62	M	W	Given as 10 years	Lower ⅓	Symptomatic	Unknown		Died shortly after admission to hospital; autopsy
3.	Moersch and Broders—1927	59	M	W	5	Lower ⅓	Symptomatic	5 months		No autopsy
4.	Voss—1928	59	M	W	21	Lower ⅓	Symptomatic	23 weeks		Autopsy
5.	Jaleski and Waldo—1935	69	M	W	6	Lower ⅓	Radiation	10 weeks		Died 30 days after onset of radiation therapy; autopsy
6.	Puyo and Portmann—1950	63	M	W	34	Lower ⅓	Resection		No follow-up	
7.	Burnett and St. John—1951	55	F	W	26	Junction middle and lower ⅓	Resection		10 months	No autopsy
8.	Chalmagne—1951	68	F	W	39	Junction middle and lower ⅓	Symptomatic	1 year		Patient alive at time of report

9	Fowler and Sutherland—1952	60	F	W	21	Lower ⅓	Resection		3 days	Autopsy
10	Garfinkle and Cahan—1952	55	F	W	21	Upper ⅓	Resection		18 days	Autopsy
11	Citterio—1953	67	M	W	13	Lower ⅓	Resection		15 months	No autopsy
12	Bullock et al—1953	71	M	W	13	Middle ⅓	Resection		4 months	Patient alive at time of report
13	Boyd et al—1954	63	M	W	10	Junction middle and lower ⅓	Resection		6 weeks	Patient alive at time of report
14	Robertson—1954	58	M	W	Given as 1½ years	Lower ⅓	Resection		12 months	Patient also had cancer of colon and rectum, autopsy
15	Sirsat—1955	40	M	Indian	52	Lower ⅓	Symptomatic	2 years		No autopsy
16	Pomeranz and Garlock—1955	48	F	W	8	Junction middle and lower ⅓	Resection	54 weeks	1 year	Patient alive and well at time of report
17	Loring and Zeppa—1955	61	F	N	17	Junction middle and lower ⅓	Resection		14 months	Patient alive at time of report

Four patients in whom resection was performed were still alive 6 weeks, 4 months, 1 year, and 14 months postoperatively. Three were symptom free. One of these patients was lost to follow-up.

The 1 patient who received radiation died within 30 days. The lesion had spread widely, and the therapy was ineffectual.

Seven of the 17 patients came to autopsy. In 4 of these, the true nature of the lesion was discovered only at that time.

Gross Findings.—The neoplasm was located in the lower third of the esophagus in 9 cases, at the junction of the middle and lower third in 5 cases, in the upper third in 2 cases, and in the middle third in 1. It most frequently presented as a polypoid tumor mass but, in one instance, had extended about two thirds of the distance around the circumference of the esophagus, and in 3 had completely encircled the lumen. Voss's report[4] described a bilobed, elongated mass that reached into the lumen of the stomach.

The typical lesion was a lobulated, pedunculated, firm, friable, black, rounded tumor mass with measurements that varied from 3 by 2 by 1 cm. to 7 by 6.8 by 2.5 cm. The pedicle averaged about 1 cm. in diameter and 2 cm. in length. The rounded surface of the neoplasm was generally smooth but was commonly the seat of small, shallow areas of ulceration that bled easily on contact with the esophagoscope. Smaller, pigmented, firm, and raised "daughter" metastases were common in the mucosa immediately surrounding the main tumor. In those instances where the main mass was large, the proximal esophagus was dilated.

The cut surface was usually found to be brown or gray-black in color with visible gray septa subdividing it. Central necrosis or hemorrhage was not common. As the tumor was usually separated from the esophageal wall by the length of the pedicle, gross evidence of invasion of the esophageal wall was usually not found. The one exception to this was the case of Puyo and Portmann,[6] where the melanocarcinoma had invaded the esophageal wall and had extended as a woody hard mass from the cardia of the stomach to a level just above the aortic arch.

Microscopic Findings.—Cellularity was marked. In only one lesion was a desmoplastic reaction described. In sections from four specimens, the tumor seemed to derive its blood supply through small vessels contained within the dividing fibrous septa.

Pleomorphism was the most striking cellular characteristic. The cells were described as being polygonal, large and elongated, round with long nuclei, and "sarcoma-like." The cytoplasm was basophilic, eosinophilic, or amphophilic. Fine cytoplasmic granules were occasionally present. In the more malignant lesions, little or no cytoplasm was visible.

Mitotic figures were present in all cases and very numerous in 3. In two specimens, meganucleosis was striking. Anisonucleosis and poikilonucleosis were found generally. Nuclear hyperchromatism and chromatin clumping were common findings. The cells were arranged in cords, clusters, fascicles, or alveolar patterns.

Iron free intracellular pigment was found in 15 of the 16 cases. It was described in macrophages in 7 cases and lying free in the intercellular spaces in 4 cases. All authors concluded that this substance was melanin by the use of one or more of the following means: (1) the characteristic appearance and location in the hematoxylin and eosin stained sections, (2) the negative reaction with special stains for iron, (3) the final black color of the granules after staining with Bielschowsky's silver nitrate method, and (4) the slow blackening effect of hydrogen peroxide.

In 9 of the 17 cases, the melanocarcinoma had invaded the submucosa and extended under the epithelium. In 4 cases, it was specifically stated that the muscle was invaded, and in 4 cases no invasion was found. Lymphatic and blood vessel penetration was not uncommon. In two specimens, however, multiple sections failed to show vessels violated by malignant cells.

Junctional changes were found in 6 cases including the 1 reported here. These were usually found in the noneroded portions of the mucosa adjacent to the tumor. Their histology ranged from hyperpigmentation and a great increase in the number of clear cells of the basal layer, resembling that seen in lentigo of the skin, to a stage identical with a fully developed junctional nevus. Usually the germinal layer and deeper portion of the stratified squamous layer contained darkly pigmented cells lying loosely in vacuolated areas. Nucleoli were prominent and the nuclei were hyperchromatic. Mitotic figures were not striking.

Sites of Metastases.—A detailed examination of the lesion and surrounding structures was made in 14 of the 17 cases either after surgical resection or at autopsy. Of these, melanocarcinoma was found in the regional lymph nodes in 11.

The available information on more distant spread was obtained from those 7 patients who came to post mortem examination. The lungs were most frequently involved, and melanocarcinomatous nodules of varying size were found in five instances. The liver and pancreas were the next most frequent sites, each being the seat of metastatic tumor in three instances. The gastrointestinal tract, brain, lumbar spine, pleura, peritoneum, lesser curvature of the stomach, retroperitoneal tissue, and left supraclavicular lymph nodes were involved in one instance each.

DISCUSSION

Primary melanocarcinoma arising in the esophagus is an uncommon and unusual lesion. The diagnosis in each of these 17 cases was made by tissue examination and is unequivocal. In every instance, a special effort was made to rule out a primary site elsewhere, and none was found. Several authors[10, 12, 13] have laid great stress on finding associated junctional epithelial changes as proof positive of autochthony, and in at least 6 of these 17 cases this transformation was present.

We, however, do not believe that this requirement is justified and agree with Robertson's observation[14] that the expanding neoplasm may well have destroyed any junctional change in those 11 specimens where it was not found. Further support is gained when one considers the rare occasion in which the esophagus is the seat of a metastatic tumor.

A consideration of possible contributory etiological factors and some of the characteristic gross findings may be made together because of their intimate relationship. Two of the 17 cases had a definite history of trauma. Puyo and Portmann's patient,[6] two years prior to the development of the malignancy, accidentally swallowed petrol with a resulting severe esophagitis. Garfinkle and Cahan's patient[10] experienced a near-fatal esophagitis and mediastinitis six years previously, following the lodgment of a chicken bone. It is difficult to believe, however, that these two incidents played a significant role in the induction of the subsequent malignant lesion.

Since by the nature of this study we can only surmise the mechanisms involved, one of the more interesting possibilities is found in the examination of *the physiology of the esophagus itself. It has been clearly shown*[17] *that, during* the third stage of the deglutition, the bolus of food is carried quickly (5 or 6 seconds in man) through the esophagus to the stomach by primary and secondary peristaltic waves. The passage through the upper third is much more accelerated than through the middle and lower thirds because of the capacity of the striated muscle in its wall for rapid contractability. It is also generally accepted that chronic irritation may play a fundamental role in the pathogenesis of melanocarcinomas elsewhere.

It would then not be unreasonable to assume that the mucosa of the lower and middle thirds of the esophagus is subject to a certain amount of chronic irritation by the rapid propulsion of food through them, especially if the food is hot, spicy, or poorly masticated.

Some support of this observation is derived from the finding of fifteen of the seventeen lesions in lower and middle thirds of the esophagus. This reasoning may also be pertinent in epidermoid carcinoma of the esophagus.

Also of interest is the observed fact that thirteen of the seventeen tumors were clearly polypoid in nature. The frequent downward push of the peristaltic waves and of the esophageal stream offers a good explanation for this characteristic gross finding. The polypoid nature of this highly malignant neoplasm may in turn explain the limited invasion of the underlying esophageal wall and the complete absence of perforation as a complication.

The obvious question as to why few people develop melanocarcinoma in the presence of such common circumstances remains unanswered and must refer back to the more fundamental nature of the lesion.

If we then review the salient historical, physical, and laboratory findings in an attempt to assemble those features that might aid in the future diagnosis of this condition, the results are of limited value.

The history was always one of a slowly expanding and gradually obstructing mass. Except for finding gross or occult blood in the stool, routine laboratory examinations were unrewarding. Although it was not always appreciated, radiologic examination often indicated the nature of the lesion. It was usually easy to outline, and its lobulated, polypoid contour tended to differentiate it from the large majority of epidermoid carcinomas. On the basis of this technique, however, one could not rule out a papilloma of the epithelium, a fibroma, polyp, or myxoma of the connective tissue, or a leiomyoma or rhabdomyoma of the muscle coat Using contrast media, the resulting filling defect in any of these conditions might be very similar in appearance The value of this examination is lessened somewhat further by the fact that these latter lesions are almost as rare as melanocarcinoma

It was found then that, although the true nature of the lesion can be suspected, a definitive clinical diagnosis can be made only by esophagoscopy, biopsy, and histologic examination

From the information given previously it is quite clear that, if patients with this disease are not treated surgically, the prognosis is universally bad Symptomatic and radiation therapy are of little value In those patients in which the lesion was successfully resected, the postoperative follow up was not sufficiently long to evaluate clearly this means of attack The data indicate, however, that as is the case in any malignant tumor, if therapy is undertaken sufficiently early, especially before the tumor has distantly metastasized, the results may be relatively satisfactory

SUMMARY

Seventeen cases of melanocarcinoma of the esophagus (16 from the world literature and 1 reported here) were studied in an attempt to consolidate all of the available clinical, diagnostic, pathologic, and prognostic data into a composite form Possible contributory etiological factors were discussed

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TRANSCAROTID AORTOGRAPHY

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THE roentgenographic visualization of the cardiovascular system using contrast media has proved of great value in the accurate diagnosis of various lesions of the heart and great vessels. Angiocardiography, with progressive visualization of all the chambers of the heart as well as the intrathoracic great vessels, has been useful particularly in the demonstration of congenital cardiovascular lesions of children. In adults, marked dilution of the injected contrast media in the blood stream and heavy x-ray penetration required for proper visualization has proved angiocardiography to be of limited application. Regional injection of concentrated contrast substances, through a properly placed needle or catheter, directly into the aorta and chambers of the heart has been used with increasing frequency. Abnormalities of the aorta, abnormal shunts, as well as valvular deformities, can be demonstrated by this method.

In 1929, Dos Santos and his associates[1] first described a satisfactory technique of translumbar abdominal aortography which is now a standard procedure of wide application. The first successful retrograde thoracic aortography was reported by Perez de Los Reyes and his co-workers in 1943.[2] A thin trocar was introduced into the left brachial artery and the radiopaque material was injected into the aorta against the arterial flow.

In 1948, Radner[3] described his technique of introducing a No. 7 to No. 9 F. cardiac catheter into the ascending aorta through the right or left radial artery. This method was developed further by Broden, Hanson, and Karnell.[4] Fifty cubic centimeters of 70 per cent Diodrast was injected manually in approximately 7 seconds. They suggested that more rapid injection of the contrast media could be obtained by using a mechanical pressure injection technique.

Burford and Carson,[5] in 1948, reported on the results of aortography performed in children. They exposed the left carotid artery and under direct visualization inserted a No. 10 cannula into the left common carotid artery and rapidly injected 30 to 50 c.c. of 70 per cent Diodrast. Excellent visualization of the aorta and its branches was obtained. Stephens[6] reported using an 18-gauge needle which was inserted into the exposed left common carotid artery with injection of 25 c.c. of 35 per cent Diodrast.

Because of difficulties encountered in using the radial artery for introduction of the cardiac catheter into the ascending aorta, Jönsson[7] abandoned this

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method of aortography and introduced a specially devised, double lumen, blunt cannula which was introduced percutaneously over a silver wire into the right common carotid artery and ascending aorta. Forty to 80 c.c. of a contrast solution could readily be injected into the aorta in 3 seconds.

In 1950, Helmsworth, McGuire, and Felson[8] utilized the brachial and ulnar collateral arteries as well as the femoral to introduce a polyethylene catheter, 50 to 70 cm. in length, into the ascending aorta. The inner diameter of the catheter was such that 8 to 30 c.c. of 70 per cent Diodrast could be injected through a 50 c.c. syringe manually in 0.7 to 1.8 seconds. Excellent visualization of the coronary vessels as well as the other branches of the aorta was obtained. Goodwin and co-workers[9] used a No. 10 F. ureteral catheter for the same purpose. Pierce,[10] in 1951, reported the use of a polyethylene tube threaded through a 17-gauge needle which in turn had been inserted into the femoral artery. Twenty to 25 c.c. of 70 per cent Diodrast was injected manually in 3 to 5 seconds.

In 1952, Wickbom[11] reported the results of aortography by direct puncture of the ascending aorta using a 13 cm. long, 1.8 mm. outside-diameter needle with manual injection of 30 to 40 c.c. of Diodrast. The time required was 3 seconds. Mediastinal hematomas occurred in several patients.

In 1954, Smith, Wilson, Cregg, and Klassen[12] reported a series of aortographies performed by percutaneous left ventricular puncture using a 17-gauge, 15 cm. needle. Twenty-five cubic centimeters of 70 per cent Diodrast was injected manually, requiring up to 3 seconds. Excellent contrast visualization of the aorta was obtained in some cases; however, the long time required for the injection prevented sufficient concentration of the contrast media to produce uniformly good aortograms.

The various techniques of aortography described in the literature were used in this Clinic with occasional excellent results but frequent failures. The difficulty of these methods is that it is impossible to inject a large enough amount of medium in the necessary second or less for good visualization of the aorta because of the small size and excessive length of the various needles and catheters. Difficulties are also encountered in the proper placement of the catheter and needle. Obliteration of the small arteries utilized for the insertion of the needles and catheters due to trauma and thrombosis is not infrequent.

A technique of thoracic aortography to be universally useful should consistently visualize the aorta from its origin to the diaphragm. The method should be safe, simple to perform, and require only surgical instruments and radiographic facilities standard in general hospitals. Rapid injection of contrast media into the ascending aorta just above the aortic valve by means of a large, short catheter inserted through the exposed right common carotid artery appeared to us to be the ideal method of aortography. Intimal damage to the aorta and carotid artery due to the presence of the catheter or contrast media would be negligible because of the large size of these vessels and the rapid flow of blood in this region. Coronary and cerebral artery filling, however, should be considered possible hazardous sequelae.

Highly concentrated solutions of contrast media used for angiocardiography at the present time may produce severe damage to tissues by acute anoxia, immediate or late toxicity, or direct chemical action. In patients without anoxemia or hypotension, brief coronary artery filling with contrast media appears to be well tolerated; however, cerebral vessel filling may produce transient or irreversible damage. Cerebral vessel filling can be kept to a minimum by occlusion of both common carotid arteries at the time of actual contrast injection.

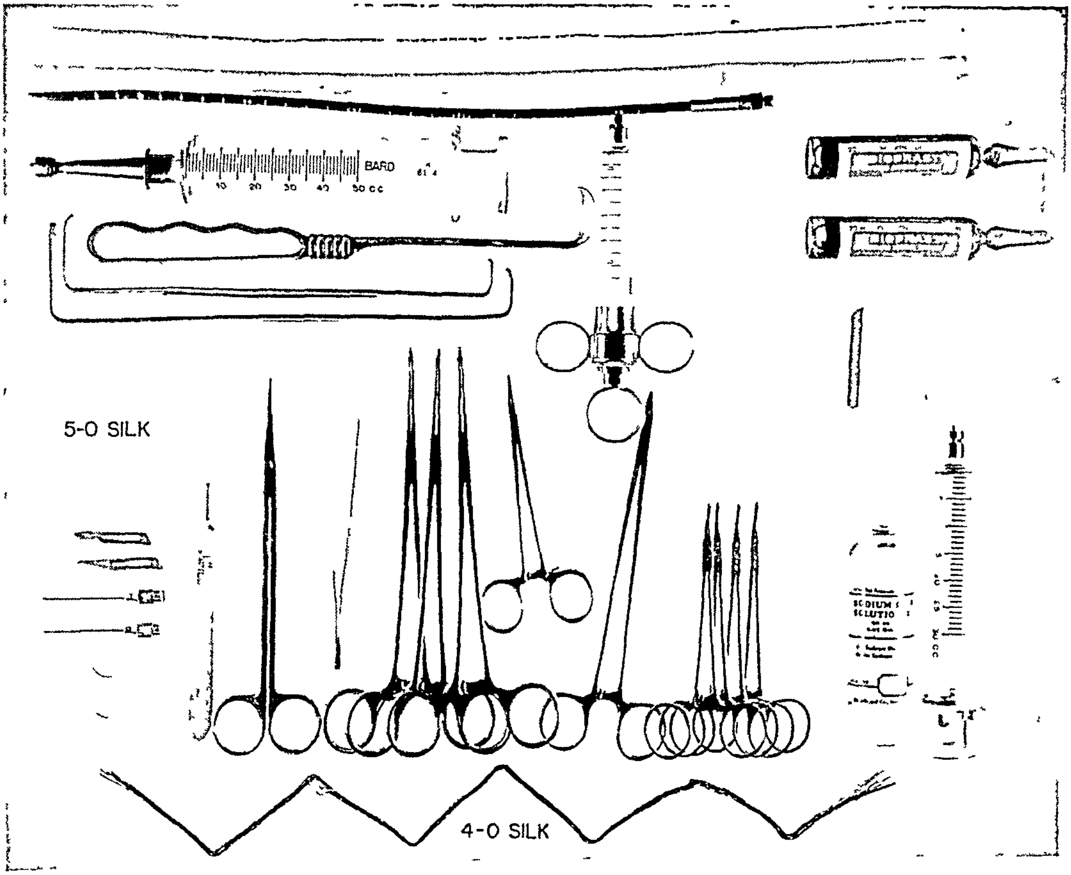

Fig. 1.—Aortography tray.

METHOD

The catheter* developed for aortography is a calibrated, radiopaque, 14 F., 35 cm. long, woven-silk catheter with a tapered lip and a Luer-Lok syringe at the proximal end (Fig. 1).

The right common carotid artery is exposed through a 2-inch incision in the skin crease at the median border of the sternocleidomastoid muscle after local injection of 1 per cent procaine solution. Following exposure of the common carotid artery, two cigarette-size Penrose drains are passed around the artery allowing it to be brought into the field. Traction on the rubber drains placed at each end of the exposed artery effectively occludes this vessel and a 3 mm. longitudinal incision in the wall of the artery will allow passage of the tip of the catheter into the innominate artery and ascending aorta. With insertion of the catheter to the 12 to 16 cm. mark, the tip will be found on fluoroscopy to be located 2 to 3 cm. above the aortic valve (Fig. 2).

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*Manufactured by C. R. Bard, Inc., Summit, N. J.

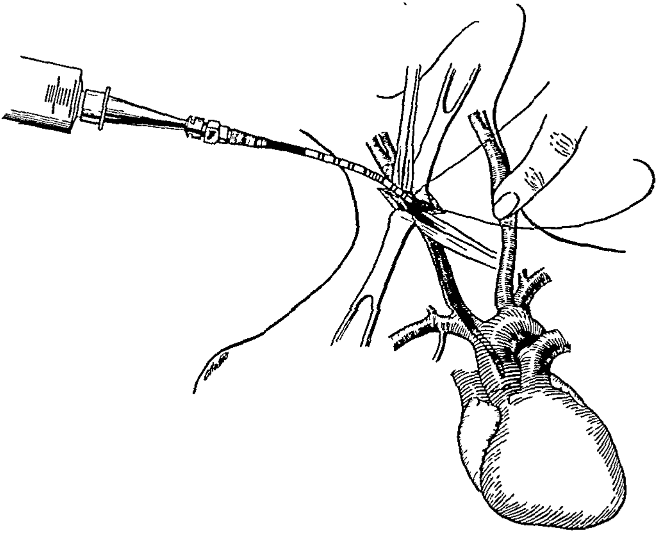
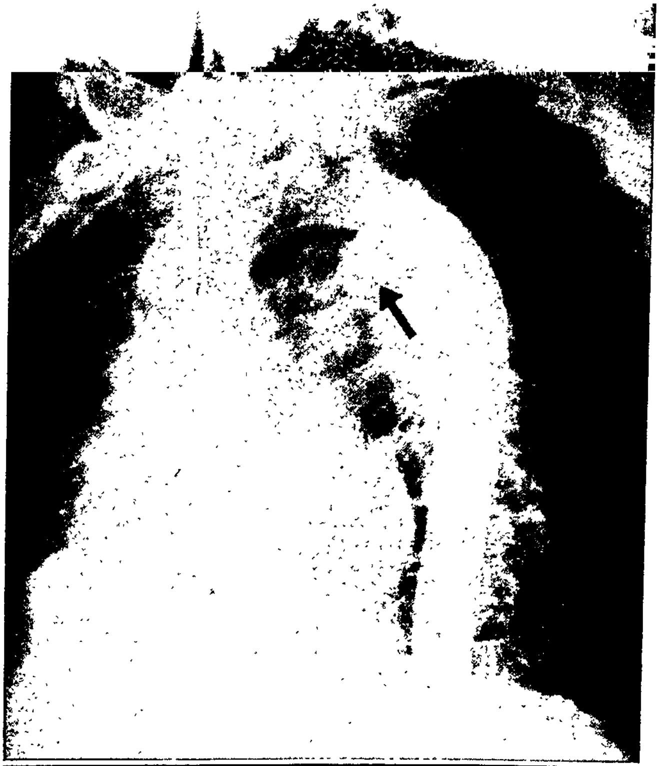


Fig. 2.—Schematic drawing of aortography technique.

Using a 50 c.c. Toomey syringe, 40 c.c. of 70 per cent Diodrast is injected manually into the aorta with the left common carotid artery occluded by finger pressure (Fig. 2). When the plunger is within 10 cm. of emptying the syringe, x-ray exposures are made either by manual change of the cassettes, or preferably, using a Fairchild film changer. On completion of the aortography the catheter is withdrawn and the incision in the carotid artery closed with a continuous suture using 5-0 silk on an Atraumatic needle. With release of tension in the Penrose drain, flow through the carotid artery resumes. The skin incision is closed with silk.

Twenty aortograms have been performed using the method just described with good results (Figs. 3 through 7). A small hematoma developed in 1 patient due to bleeding from a small cervical vein which had not been ligated properly during exposure. In 1 patient, no visualization was obtained due to mechanical failure.

Fig. 3.



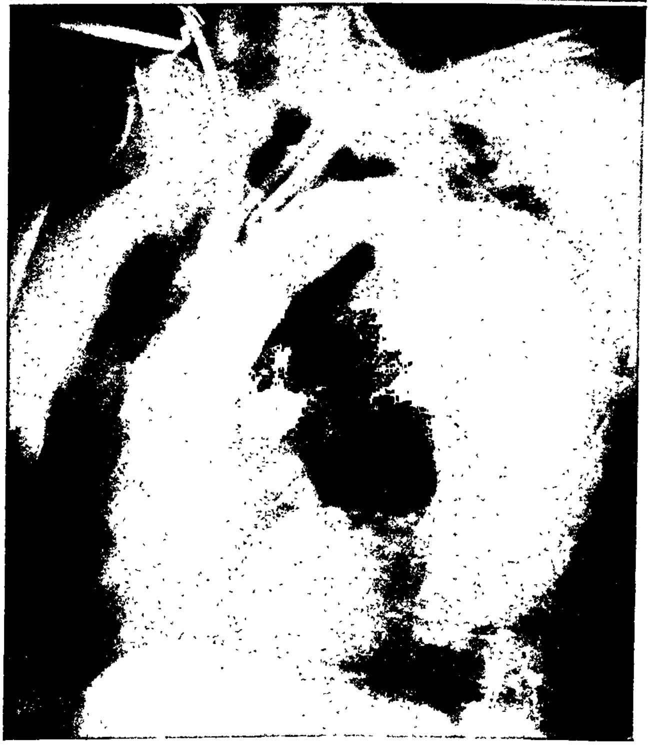
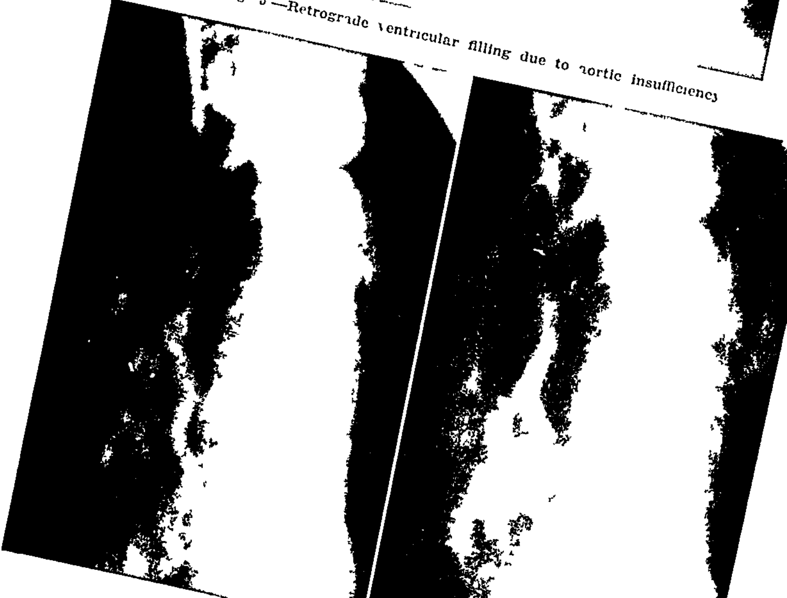


Fig. 4.

Fig. 3.—Aneurysmal dilatation of ductus arteriosus.
Fig. 4.—Aneurysm of descending aorta.

Fig 5 —Retrograde ventricular filling due to aortic insufficiency



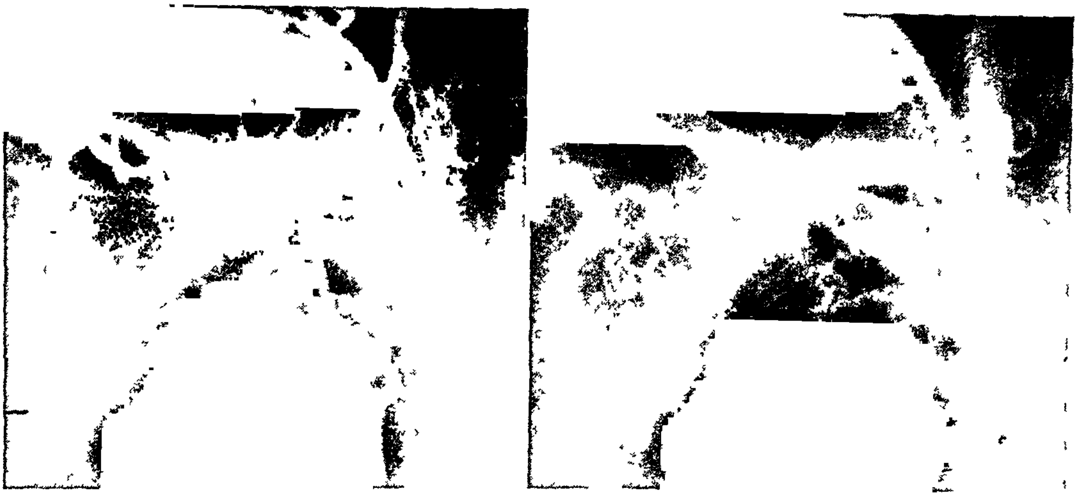


Fig 7.—Right subclavian artery occlusion.

SUMMARY

A method of transcarotid thoracic aortography utilizing a catheter placed into the ascending aorta has been described. Aortography by this method using 70 per cent Diodrast has given excellent visualization of the entire thoracic aorta.

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THE PHYSIOLOGIC EFFECTS OF FIBROTHORAX AND THE FUNCTIONAL RESULTS OF SURGICAL TREATMENT

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WITH THE TECHNICAL ASSISTANCE OF BETTY L VESTAL
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INTRODUCTION

PLEURAL decortication is an established method for restoring the apposition of the pleural surfaces, thus obliterating an abnormal pleural space In addition to meeting this therapeutic objective, the operation frequently results in significant improvement in the respiratory status of the patient A number of studies have appeared in which the procedure is evaluated from a functional point of view [1-5] A concise review of these may be found in the introductory paragraphs of the publication by Patton and his associates[3]

This report concerns an additional study of the physiologic effects of pleural abnormalities and their surgical treatment Few patients with lungs imprisoned by tuberculous or nontuberculous pleural peels have been evaluated comprehensively Some of the most complete studies have suffered from a lack of pre to postoperative comparisons[1, 4] and in others the data are limited to ventilation, vital capacity, and oxygen uptake[2, 3] Among the papers referred to, only 4 patients are cited[1, 5] in whom pre and postoperative tests include total lung capacities, bronchospirometry, and gas analysis of arterial blood

The data recorded from the present 11 patients pertain to pre and post operative unilateral and bilateral ventilation and total lung capacities as well as to characteristics of gas exchange The measurements of the maximum diffusing capacity and the determinations of the unilateral residual volume have not, to our knowledge, been reported previously in such patients

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From the Cardiopulmonary Function Laboratory United States Naval Hospital St Albans N Y

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MATERIAL

Eleven patients for whom decortication was the major thoracic surgical procedure were studied in the Cardiopulmonary Function Laboratory of the United States Naval Hospital, St. Albans, New York. A bacteriologic diagnosis of tuberculosis was established in 5 of these and in an additional patient (No. 9) the diagnosis of tuberculosis was made on histologic grounds without bacteriologic verification (Table I). In the other 5 patients, the constricting peel was considered to be nontuberculous in origin. A summary of other pertinent clinical data is included in Table I. Ten of the 11 patients were men; only 1 of these exceeded 35 years of age. There were nine Caucasians and two Negroes.

The involvement was unilateral in all patients. The right chest was the site of the pathology in 5 patients and the left side in 6. The duration of the disorder prior to operation ranged from two months in Patient 4 to thirteen years in Patient 6. In all but 2 patients the abnormality had been recognized less than one year prior to surgery. The period of convalescence before the postoperative study was three months or less in all but three instances. Most of the patients, therefore, were young men with a unilateral pleural membrane uncomplicated by parenchymal involvement in whom the postoperative study was carried out relatively early after decortication.

Four patients were selected in order to illustrate (a) physiologic improvement following decortication for nontuberculous empyema (Patient 2, Figs. 1*A* and 1*B*) and tuberculous empyema (Patient 11, Figs. 2*A* and 2*B*); (b) functional changes following decortication performed for long-standing parenchymal disease treated with pneumothorax (Patient 8, Figs. 3*A* and 3*B*); and (c) unfavorable results of operation in a patient with only moderate preoperative impairment due to a chronic "nontuberculous" pleural membrane (Patient 3, Figs. 4*A* and 4*B*).

Clinical data pertaining to these 4 illustrative cases follow in summary form.

CASE REPORTS

Patient 2, a 20-year-old white man, developed fever and extreme chest pain in April, 1952. Physical examination and roentgenograms revealed the presence of a left-sided pleural effusion. Under chemotherapy he became asymptomatic and afebrile but the roentgenographic signs of the effusion persisted. In July, a thoracentesis yielded 900 c.c. of fluid which on smear and culture was negative for acid-fast bacilli and other pathogenic organisms.

A left thoracotomy was performed in August, 1952. A chronic empyema was found with the lung entrapped by a thick peel. Decortication was done following which the lung re-expanded well. The postoperative course was uneventful.

Patient 11, a 23-year-old Negro man, was well until April, 1953, when he developed pain in the left chest on deep inspiration. Physical examination and a roentgenogram of the chest showed a left pleural effusion. Fluid aspirated was positive for acid-fast bacilli on culture. He was treated with bed rest, repeated thoracenteses, streptomycin and para-aminosalicylic acid. In October, 1953, decortication was performed. Two weeks after the operation, the seventh intercostal space was explored, an extrapleural abscess cavity was found and the involved cartilage and rib were resected. The postoperative course was uneventful.

Patient 8, a 41-year-old white man, was first found to have pulmonary tuberculosis in 1944 with involvement of the right lung. He was treated with right phrenic crush and nine

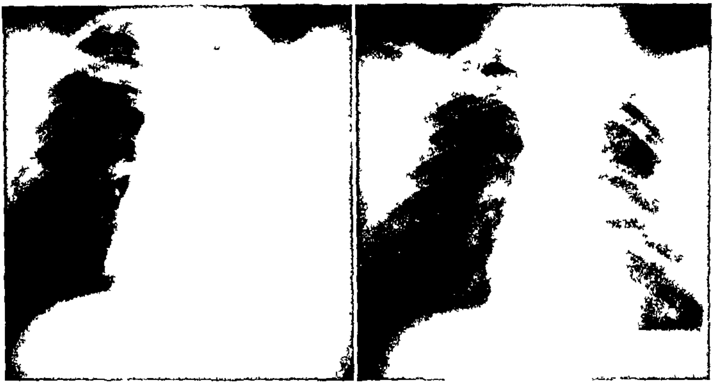

Fig 1A.—Chest roentgenograms of Patient No 2 taken before (left) and after (right) decortication of the left lung for a nontuberculous empyema. Corresponding functional data are presented in Fig 1B.

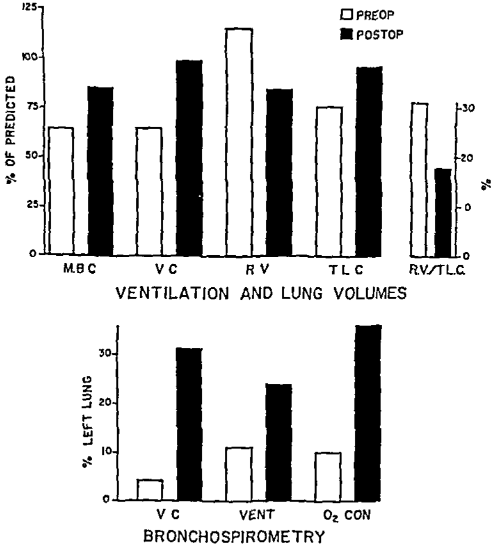

Fig
Patient 2
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The fall

bars) and postoperative (solid bars) function data of
ximum breathing capacity (M B C) and unilateral partici
increased vital capacity (V C) and total lung capacity
ribution of the left lung to oxygen consumption (O Con)
is atypical (see Figs 2B and 3B)

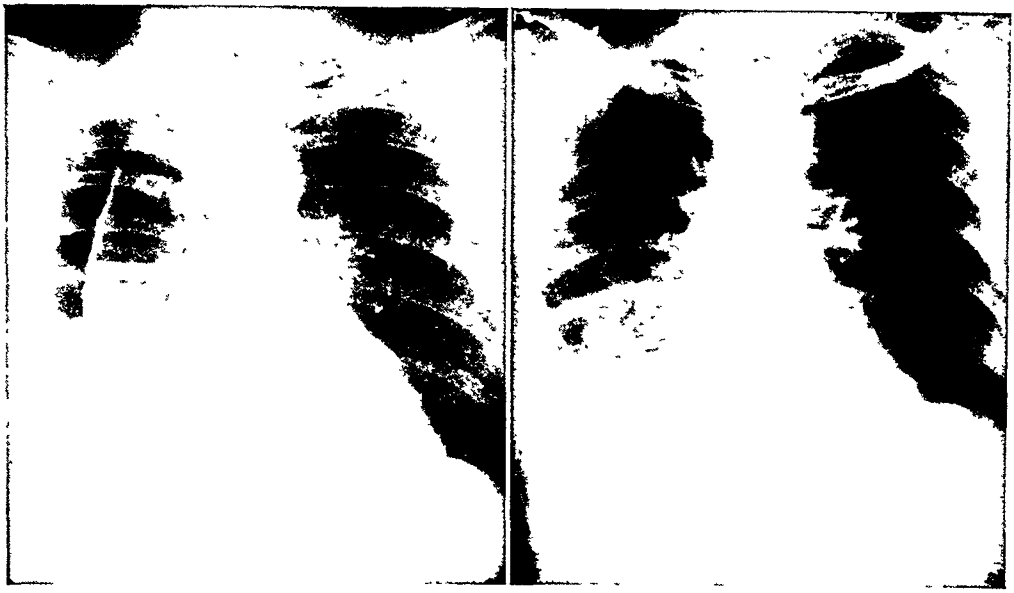
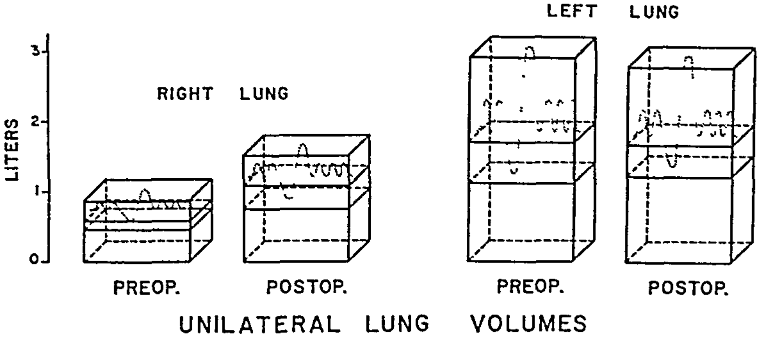


Fig. 3A.—Chest roentgenograms of Patient 8 taken before (left) and after (right) decortication of the right lung. There had been pneumothorax intermittently for nine years and persistent tuberculous pleural effusion for seven years. Corresponding functional data are presented in Fig. 3B.



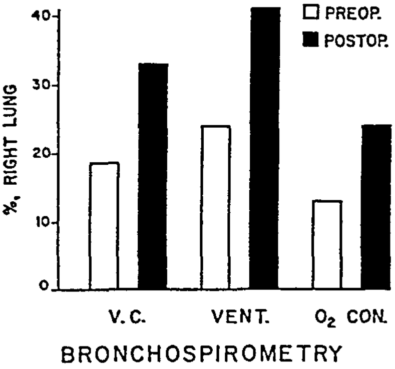


Fig. 3B.—Pre- and postoperative unilateral function data of Patient 8. Three-dimensional figures indicate the subdivisions of the total volume of each lung. A tracing of the spirogram identifies the volume of the lung at the end-expiratory position (Functional Residual Capacity or F.R.C.), after maximal inspiration (Total Lung Capacity), and following a maximal expiration (Residual Volume or R.V.). These volumes are labeled in Fig. 4B. Note the increase in all volumetric compartments of the right lung in consequence of decortication and re-expansion. Bronchospirometry indicates an augmented contribution of this lung to vital capacity (V.C.), ventilation (Vent.), and oxygen uptake (O_2 Con.) despite the prolonged duration of right pleural disease.

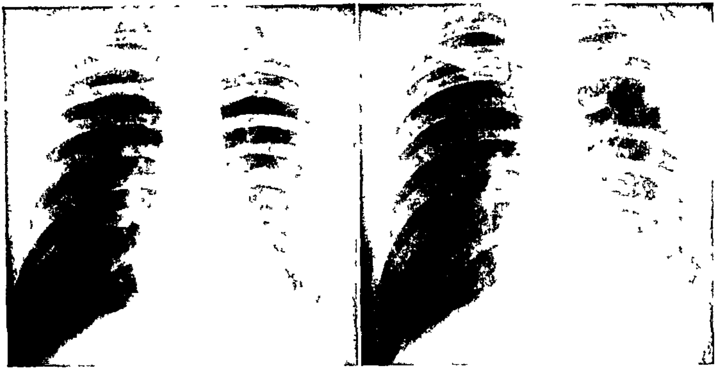


Fig 4*A*.—Pre- and postoperative chest roentgenograms of Patient 3 A sterile pleural effusion had persisted on the left for seven and one-half months The postoperative film was made three weeks after decortication, coincidentally with the postoperative studies represented in Fig 4*B*.

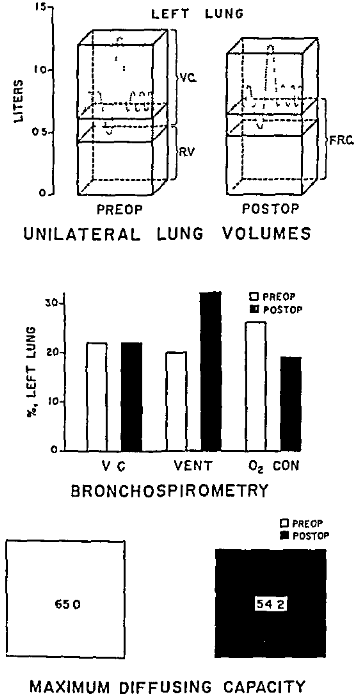


Fig. 4*B*—Pre- and postoperative function data of Patient 3 The interpretation of the volumetric figures corresponds to that for Fig 3*B* At the time of the postoperative study, the volumetric compartments of the left lung were virtually identical with those measured preoperatively Bronchospirometry indicates the moderate preoperative deficit, the improved contribution of the left lung to ventilation, and the further impairment in oxygen consumption The latter was associated with a fall in the maximum diffusing [illegible] V.C., [illegible] Capacity, R V, Residual Volume; F R C, Functional Residual Capacity.

If, in patients with normal alveolar-capillary membranes and normal alveolar oxygen partial pressures, one assumes that peripheral blood is a mixture of two streams, one being mixed venous blood and the other arterial blood in equilibrium with alveolar air, the venous admixture figure indicates the fraction of mixed venous blood which, if added to the equilibrated arterial blood, would account for the peripheral arterial saturation actually measured. Patients in whom variations in ventilation-perfusion relationships in different parts of the lungs are abnormally great have dead space ventilations exceeding 30 per cent of the tidal volume and venous admixture components above 6 per cent.

The diffusing capacity is the amount of oxygen passing across the alveolar-capillary membrane per unit of pressure difference between the two sides of this membrane. It is obtained by measuring the oxygen consumption and deriving the effective partial pressure (tension) of oxygen in alveoli and in pulmonary capillaries. The alveolar value is calculated by solving the alveolar equation.[10] The capillary tension is found by measuring the partial pressure of oxygen in arterial blood (Pa_{O_2}) when it closely approximates that in the pulmonary capillaries. Circumstances under which this is true are created by reducing the oxygenation of the patient's peripheral arterial blood; this is usually accomplished by a combination of exercise and breathing a gas mixture abnormally low in its content of oxygen. From the alveolar and capillary oxygen partial pressures and from an assumed figure for the saturation of mixed venous blood, it is possible to derive a mean value for the oxygen tension gradients existing along the course of the pulmonary capillary. The diffusing capacity is the oxygen consumption divided by this mean gradient. The *maximum* diffusing capacity for a given individual is reached when oxygen consumption is increased to approximately 1,200 c.c. per minute.[12] Under these circumstances, and when the permeability of the alveolar-capillary membrane is not altered by disease, the diffusing capacity is a function of the maximal dimensions of the alveolar-capillary bed.[13] The maximum diffusing capacities in nine young men, with minimal or no pulmonary pathology, studied in this laboratory ranged from 68 to 86 with a mean of 76.[13]

Blood gas tension analyses were done by the bubble-equilibration technique[14] and the composition of expired gases was determined with the Scholander apparatus.[15] Blood gas contents and the concentrations of nitrogen in samples of air were measured by the Van Slyke manometric technique.

Lung volumes were corrected to body temperature, ambient pressure, saturated with water vapor (BTPS). The nomenclature used in referring to functional data is that suggested for workers in the field.[16]

The following abbreviations appear in Tables II and IV:

Ventilation, Bil., L./m./M^2 B.S.A.—Bilateral ventilation in liters per minute per square meter of body surface area, BTPS

Ventilation, Rt. %, Lt. %—Contribution of each lung to total ventilation in per cent

M.B.C., L./m.—Maximum breathing capacity in liters per minute, BTPS

M.B.C., % of Pred.—The maximum breathing capacity as per cent of the predicted value

V.C.—Vital capacity

R.V.—Residual volume

T.L.C.—Total lung capacity

F.R.C.—Functional residual capacity

R.V./T.L.C.—Ratio of the residual volume to the total lung capacity in per cent

F.R.C./T.L.C.—Ratio of the functional residual capacity to the total lung capacity in per cent

Mixing Index, Vols. % N_2—Mixing index in volumes per cent nitrogen

BP–47—Barometric pressure minus correction for water vapor tension of air saturated at body temperature, in millimeters of mercury

$F_{I_{O_2}}$—Concentration of oxygen in inspired air

$F_{E_{CO_2}}$—Concentration of carbon dioxide in expired air in per cent

V—Total ventilation in liters per minute, BTPS

f—Respiratory frequency (breaths per minute)

R—The gas exchange ratio or respiratory quotient, i e, carbon dioxide output divided by the oxygen consumption

Pa_{CO}—Partial pressure of carbon dioxide in arterial blood in millimeters of mercury

Ca_{CO}—Cubic centimeters of carbon dioxide contained in 100 cubic centimeters of arterial blood

P_{A_O}—Partial pressure of oxygen in alveolar air in millimeters of mercury

Pa_{O_2}—Partial pressure of oxygen in arterial blood in millimeters of mercury

Sa_O—Oxyhemoglobin saturation of arterial blood in per cent

V_O—Oxygen consumption in cubic centimeters per minute, STPD (standard temperature and pressure, dry)

V_{D_T} Total cc—Physiologic dead space volume in cubic centimeters, corrected for apparatus dead space

V_{D_T} M², cc—Physiologic dead space volume in cubic centimeters per square meter of body surface area

$(V_{D_T}/V_T) \times 100$—Ratio of dead space to tidal volume in per cent

$(Q_a/Q_t) \times 100$—Ratio of the venous admixture to cardiac output in per cent

RESULTS

Ventilation and Lung Volumes (Tables I and II)

The evaluation of the 11 patients with respect to ventilation and lung volumes (Table II) is presented below under three headings (1) the effect of a constricting pleural peel, (2) the effect of operation, and (3) the postoperative status

1 *Effect of a Constricting Pleural Peel*—*Ventilation at rest* was abnormal in only 1 patient (No 2) However, the contribution of the affected lung to ventilation was abnormally low in all patients studied preoperatively (below 40 per cent for the right lung in patients with involvement on the right side and less than 30 per cent for the left lung where this was the affected side) The *maximum breathing capacity* was below 90 per cent of the predicted value in 9 of the 11 patients and below 80 per cent of predicted in 7 This test was therefore a more useful index for detecting abnormalities in bilateral ventilation than was ventilation at rest

Lung volume determinations indicated a restriction of the vital capacity below 80 per cent of the predicted value in 7 of the 11 patients, no elevation of the residual volume in excess of 140 per cent of predicted, and a decrease of the total lung capacity below 80 per cent of predicted in 7 patients In only two instances was the ratio of the residual volume to the total lung capacity abnormally high (over 30 per cent) The vital capacity of the affected lung was grossly abnormal (below 40 per cent on the right or 30 per cent on the left) in each of the 9 patients with preoperative studies

The *mixing index* was normal in all patients

Comparison of the patients in the tuberculous and nontuberculous groups indicated *no striking differences* with respect to performance on these tests

If, in patients with normal alveolar-capillary membranes and normal alveolar oxygen partial pressures, one assumes that peripheral blood is a mixture of two streams, one being mixed venous blood and the other arterial blood in equilibrium with alveolar air, the venous admixture figure indicates the fraction of mixed venous blood which, if added to the equilibrated arterial blood, would account for the peripheral arterial saturation actually measured. Patients in whom variations in ventilation-perfusion relationships in different parts of the lungs are abnormally great have dead space ventilations exceeding 30 per cent of the tidal volume and venous admixture components above 6 per cent.

The diffusing capacity is the amount of oxygen passing across the alveolar-capillary membrane per unit of pressure difference between the two sides of this membrane. It is obtained by measuring the oxygen consumption and deriving the effective partial pressure (tension) of oxygen in alveoli and in pulmonary capillaries. The alveolar value is calculated by solving the alveolar equation.[10] The capillary tension is found by measuring the partial pressure of oxygen in arterial blood ($P_{a_{O_2}}$) when it closely approximates that in the pulmonary capillaries. Circumstances under which this is true are created by reducing the oxygenation of the patient's peripheral arterial blood; this is usually accomplished by a combination of exercise and breathing a gas mixture abnormally low in its content of oxygen. From the alveolar and capillary oxygen partial pressures and from an assumed figure for the saturation of mixed venous blood, it is possible to derive a mean value for the oxygen tension gradients existing along the course of the pulmonary capillary. The diffusing capacity is the oxygen consumption divided by this mean gradient. The *maximum* diffusing capacity for a given individual is reached when oxygen consumption is increased to approximately 1,200 c.c. per minute.[12] Under these circumstances, and when the permeability of the alveolar-capillary membrane is not altered by disease, the diffusing capacity is a function of the maximal dimensions of the alveolar-capillary bed.[13] The maximum diffusing capacities in nine young men, with minimal or no pulmonary pathology, studied in this laboratory ranged from 68 to 86 with a mean of 76.[13]

Blood gas tension analyses were done by the bubble-equilibration technique[14] and the composition of expired gases was determined with the Scholander apparatus.[15] Blood gas contents and the concentrations of nitrogen in samples of air were measured by the Van Slyke manometric technique.

Lung volumes were corrected to body temperature, ambient pressure, saturated with water vapor (BTPS). The nomenclature used in referring to functional data is that suggested for workers in the field.[16]

The following abbreviations appear in Tables II and IV:

Ventilation, Bil., L./m./M^2 B.S.A.—Bilateral ventilation in liters per minute per square meter of body surface area, BTPS

Ventilation, Rt. %, Lt. %—Contribution of each lung to total ventilation in per cent

M.B.C., L./m.—Maximum breathing capacity in liters per minute, BTPS

M.B.C., % of Pred.—The maximum breathing capacity as per cent of the predicted value

V.C.—Vital capacity

R.V.—Residual volume

T.L.C.—Total lung capacity

F.R.C.—Functional residual capacity

R.V./T.L.C.—Ratio of the residual volume to the total lung capacity in per cent

F.R.C./T.L.C.—Ratio of the functional residual capacity to the total lung capacity in per cent

Mixing Index, Vols. % N_2—Mixing index in volumes per cent nitrogen

BP-47—Barometric pressure minus correction for water vapor tension of air saturated at body temperature, in millimeters of mercury

$F_{I_{O_2}}$—Concentration of oxygen in inspired air

$F_{E_{CO_2}}$—Concentration of carbon dioxide in expired air in per cent

V—Total ventilation in liters per minute, BTPS

f—Respiratory frequency (breaths per minute)

R—The gas exchange ratio or respiratory quotient, i.e., carbon dioxide output divided by the oxygen consumption

Pa_{CO}—Partial pressure of carbon dioxide in arterial blood in millimeters of mercury

Ca_{CO}—Cubic centimeters of carbon dioxide contained in 100 cubic centimeters of arterial blood

$P_{A_{O_2}}$—Partial pressure of oxygen in alveolar air in millimeters of mercury

Pa_{O}—Partial pressure of oxygen in arterial blood in millimeters of mercury

Sa_{O}—Oxyhemoglobin saturation of arterial blood in per cent

V_{O}—Oxygen consumption in cubic centimeters per minute, STPD (standard temperature and pressure, dry)

V^{e}_{D} Total, c.c.—Physiologic dead space volume in cubic centimeters corrected for apparatus dead space

V^{e}_{D}, M², c.c.—Physiologic dead space volume in cubic centimeters per square meter of body surface area

$(V^{e}_{I}/V_{T}) \times 100$—Ratio of dead space to tidal volume in per cent

$(Q_{va}/Q_{t}) \times 100$—Ratio of the venous admixture to cardiac output in per cent

RESULTS

Ventilation and Lung Volumes (Tables I and II)

The evaluation of the 11 patients with respect to ventilation and lung volumes (Table II) is presented below under three headings: (1) the effect of a constricting pleural peel, (2) the effect of operation, and (3) the postoperative status.

1. *Effect of a Constricting Pleural Peel.—Ventilation at rest* was abnormal in only 1 patient (No. 2). However, the contribution of the affected lung to ventilation was abnormally low in all patients studied preoperatively (below 40 per cent for the right lung in patients with involvement on the right side and less than 30 per cent for the left lung where this was the affected side). The *maximum breathing capacity* was below 90 per cent of the predicted value in 9 of the 11 patients and below 80 per cent of predicted in 7. This test was therefore a more useful index for detecting abnormalities in bilateral ventilation than was ventilation at rest.

Lung volume determinations indicated a restriction of the vital capacity below 80 per cent of the predicted value in 7 of the 11 patients, no elevation of the residual volume in excess of 140 per cent of predicted, and a decrease of the total lung capacity below 80 per cent of predicted in 7 patients. In only two instances was the ratio of the residual volume to the total lung capacity abnormally high (over 30 per cent). The vital capacity of the affected lung was grossly abnormal (below 40 per cent on the right or 30 per cent on the left) in each of the 9 patients with preoperative studies.

The *mixing index* was normal in all patients.

Comparison of the patients in the tuberculous and nontuberculous groups indicated *no striking differences* with respect to performance on these tests.

TABLE I. BODY CHARACTERISTICS AND CLINICAL DATA IN 11 PATIENTS TREATED BY PULMONARY DECORTICATION

PATIENT NUMBER	AGE	SEX	RACE	B.S.A.	DIAGNOSIS	SIDE	DURATION (MONTHS)	TBC OR NON-TBC	PARENCHYMAL LESION	BACTERIOLOGY	POSTOPERATIVE COMPLICATIONS	SECOND STUDY (MOS. POSTOP.)
1	21	M	Cauc.	1.79	Empyema, organism undeter.	Lt.	4	Non	No	–	Complete paralysis, lt. hemidiaphragm; empyema	8½
2	20	M	Cauc.	1.97	Empyema, chronic, nontuberc.	Lt.	4	Non	No	–	None	10
3	24	M	Cauc.	1.92	Pleurisy, chronic, organism undeter.	Lt.	7½	Non	No	–	None	¾
4	33	M	Cauc.	2.03	Empyema, organism undeter.	Rt.	2	Non	No	–	None	1½
5	33	M	Negro	1.73	Pleurisy, chronic, organism undeter.	Rt.	4	Non	No	–	None	2
6	38	F	Cauc.	1.54	Pleurisy, tuberc.; pulm. TBC, RUL, sup. seg. RLL, inact.	Rt.	13 yrs.	TBC	Yes, not resected	+	None	5
7	22	M	Cauc.	2.06	Pleurisy, tuberc., chronic; arthritis, tuberc., lt. knee	Rt.	4½	TBC	No	+	None	2½
8	41	M	Cauc.	2.00	Pleurisy, tuberc., chronic; pulm. TBC, mod. adv., chronic	Rt.	7 yrs.	TBC	Yes, removed by wedge resection	+	None	2½
9	22	M	Cauc.	2.04	Pleurisy, tuberc., chronic	Lt.	8½	TBC	No	–	None	2½
10	22	M	Cauc.	1.70	Empyema, tuberc.; pulm. TBC, minimal	Lt.	6	TBC	Yes, removed by wedge resection	+	Bronchopleural fistula	2¼
11	23	M	Negro	1.78	Empyema, tuberc., pulm. TBC, mod. act., RUL; TBC of bone, 7th costal cartilage	Lt.	6	TBC	Yes, not resected	+	None	3

Table II. Pre- and Postoperative Unilateral and Bilateral Ventilation and Lung Volumes in 11 Patients Treated by Pulmonary Decortication

			VENTILATION					LUNG VOLUMES									VOLUMETRIC RATIOS, %		MIXING INDEX	OXYGEN UPTAKE	
			AT REST			MBC		V.C.				R.V.		T.L.C.		F.R.C.					
PATIENT NO.		AFFECTED SIDE	BIL., L/m /M² BSA*	RT. (%)	LT. (%)	L/m	% OF PRED.	BIL. C.C.	% OF PRED.	RT. (%)	LT. (%)	BIL. C.C.	% OF PRED.	BIL. C.C.	% OF PRED.	BIL. C.C.	R.V./ T.L.C.	F.R.C./ T.L.C.	VOLS. % N₂	RT. (%)	LT. (%)
1	Pre	Lt.	3.2	--	--	79	58	2740	60	--	--	1099	96	3839	68	1813	29	47	1.35	--	--
	Post		4.6	69	31	99	72	3235	71	80	20	1473	129	4708	82	2209	31	47	1.14	74	26
2	Pre	Lt.	5.0	89	11	96	64	3029	65	96	4	1363	117	4392	76	1992	31	45	0.68	90	10
	Post		4.9	76	24	130	86	4580	99	69	31	975	84	5555	96	1920	18	35	0.52	64	36
3	Pre	Lt.	3.2	80	20	92	65	3331	74	78	22	1104	98	4435	79	1924	25	43	0.86	74	26
	Post		4.4	68	32	129	91	3005	67	78	22	1360	121	4365	78	2070	31	47	0.98	81	19
4	Pre	Rt.	3.7	38	62	159	113	3607	85	30	70	1483	139	5090	96	2072	29	41	1.10	37	63
	Post		6.5	57	43	153	109	3822	90	38	62	1761	166	5583	105	2281	32	41	0.65	53	47
5	Pre	Rt.	3.3	36	64	101	84	2242	57	20	80	759	77	3001	61	1304	25	43	0.98	24	76
	Post		3.3	44	56	145	121	2862	73	31	69	879	89	3741	76	1389	23	37	0.68	50	50
6	Pre	Rt.	3.8	--	--	69	84	2501	90	--	--	1070	126	3571	98	1613	30	45	1.35	--	--
	Post		2.4	55	45	85	101	2443	88	40	60	1232	145	3675	101	1782	34	48	3.23	24	76
7	Pre	Rt.	4.6	11	89	73	47	2375	49	8	92	784	65	3159	53	1131	25	36	0.61	17	83
	Post		3.9	41	59	144	93	3096	64	36	64	2061	172	5157	86	2623	40	51	0.55	40	60
8	Pre	Rt.	4.4	24	76	62	48	3310	81	19	81	1710	137	5020	94	2405	34	48	1.59	13	87
	Post		3.4	41	59	67	52	3415	84	33	67	1885	150	5300	100	2635	35	50	2.24	24	76
9	Pre	Lt.	6.4	78	22	120	78	4115	90	85	15	740	65	4855	85	1625	15	33	0.60	82	18
	Post		6.3	68	32	116	76	4180	91	71	29	1321	115	5501	96	2121	24	39	0.53	84	16
0	Pre	Lt.	5.3	94	6	75	59	2788	64	91	9	994	92	3782	70	1633	26	43	1.14	93	7
	Post		4.5	86	14	106	83	3234	74	78	22	1281	118	4515	83	2060	28	46	0.74	82	18
1	Pre	Lt.	4.1	87	13	131	98	2546	57	90	10	846	76	3392	61	1397	25	41	0.99	93	7
	Post		3.6	68	32	135	102	2941	66	71	29	1016	91	3980	71	1790	25	45	0.76	70	30

*See text under "Methods" for explanations of abbreviations used.

Summary: Restrictions of ventilation existed on the side of the lesion in all patients with bronchospirometric measurements. The total vital capacity was usually abnormally low and the unilateral vital capacity, where measured, was invariably low. The residual volume was also commonly reduced; it infrequently comprised a larger proportion of the total lung capacity than normal. No instance of impaired intrapulmonary mixing was found. No clear distinction could be made between patients on the basis of etiology.

2. *Effect of Operation.—Ventilation at rest* was found to increase by 15 per cent or more in 3 and decrease by 15 per cent or more in 5 patients, no significant change being noted in the other 3 patients. The contribution of the affected lung to ventilation increased by 8 per cent or more in each of 9 patients with pre- to postoperative comparisons (mean increase 15 per cent, maximum 30 per cent, minimum 8 per cent). The *maximum breathing capacity* increased by more than 15 L. (maximum, 71 L.; minimum, 16) in 7 of the 11 cases. In the other 4 the pre- to postoperative change was 6 L. or less.

The *vital capacity* increased by 16 per cent* or more (maximum 51 per cent, minimum 16 per cent) in 6 patients. In the remaining 5, the change was 10 per cent or less and was not considered significant. The residual volume increased by 15 per cent or more (maximum 163 per cent, minimum 15 per cent) in 9 patients, fell by more than 15 per cent in 1 patient, and remained unchanged (10 per cent) in 1. The total lung capacity increased by 10 per cent or more (maximum 63 per cent, minimum 10 per cent) in 8 patients and was insignificantly changed (less than 10 per cent) in the other 3. The ratio of the residual volume to the total lung capacity was increased by more than 3 per cent in 4 patients, fell by more than 3 per cent in 1, and was changed by less than 3 per cent in the remaining 6. Eight of 9 patients with pre- to postoperative unilateral vital capacity determinations showed an increase in the per cent contributed by the affected lung exceeding 8 per cent (mean 17 per cent, minimum 8 per cent, maximum 26 per cent); 1 patient showed no change (No. 3). The functional residual capacity increased by 10 per cent or more (maximum 132 per cent, minimum 10 per cent) in 8 patients and showed a change of less than 10 per cent in the other 3.

The *mixing index* increased to an abnormally high value (3.23 per cent) in 1 patient; this index had been normal preoperatively.

As previously noted, the ventilation at rest fell in 5 of the 11 patients; all of these had tuberculosis. With this single exception, no remarkable differences in tests of bilateral function were noted between the pre- to postoperative changes in the tuberculous and nontuberculous groups. With respect to bronchospirometry, however, inspection of Table II shows that the greatest improvement of the affected lung was noted in patients in the tuberculosis group. It is likely that this is attributable to the fact that these patients showed the poorest preoperative function.

Summary: Participation of the affected lung in ventilation at rest was increased by decortication. This was a more consistent finding than improved maximum breathing capacity and occurred independently of the latter. The residual volume and the functional residual capacity usually increased, this change occurring more frequently than improvement of the vital capacity. The proportion of the vital capacity contributed by the affected lung usually rose significantly. With one exception, intrapulmonary mixing was not adversely affected. Improvement of unilateral ventilation and volume was most conspicuous in patients with the severest preoperative deficit.

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*Percentages were computed by dividing the pre- to postoperative change by the preoperative value.

3. Postoperative Status.—Ventilation at rest was normal (below 5.0 L./minute/square meter body surface area) in 9 patients. Participation of the affected side, however, remained low in all patients except two (No. 4 and No. 6). In 9, the abnormality was such that the right lung contributed less than 50 per cent when it was the site of disease and the left lung less than 40 per cent when the left side was affected. These values had been below these levels in 8 of the 9 patients with preoperative studies. The *maximum breathing capacity* was less than 90 per cent of the predicted value in 5 of the 11 patients and less than 80 per cent in 3; it was over 90 per cent of predicted in 6.

Lung volumes: The vital capacity remained below 80 per cent of the predicted value in 6 of the 11 patients and was 90 per cent or more of predicted in three instances. The total lung capacity was less frequently so low, values below 80 per cent of those predicted being found in 3 patients. The residual volume was usually normal; in only 2 patients was a figure exceeding 150 per cent of predicted recorded. The ratio of the residual volume to the total lung capacity exceeded 30 per cent in 6 patients. In 5 of these, this ratio had been normal preoperatively. The affected lung of 10 patients remained grossly abnormal with respect to its contribution to the vital capacity (less than 41 per cent on the right in patients with right-sided involvement and less than 30 per cent on the left when this was the affected side). No patient showed a normal distribution of the vital capacity postoperatively.

All patients except 1 (No. 6) had a normal *mixing index* postoperatively.

Summary: Abnormalities of ventilation and vital capacity were the rule rather than the exception in patients studied postoperatively. These were detected more frequently by unilateral measurements than by the bilateral techniques. The residual volume and the index of intrapulmonary mixing were usually normal; the vital capacity was usually low. Comparison of tuberculous and nontuberculous groups indicated no striking differences with respect to respiratory status.

Studies of the Unilateral Total Lung Capacity (Table III)

Two patients (No. 3 and No. 8) had acceptable pre- and postoperative studies of the unilateral total lung capacity and a third (No. 9) had a satisfactory postoperative study only. Patient 8 (Fig. 3) showed a good postoperative result, that is, his vital capacity increased from 19 to 33 per cent on the side of the operation and the oxygen consumption from 13 to 24 per cent. Correspondingly, the functional residual capacity of the right lung increased 184 per cent and the residual volume 166 per cent of the preoperative value. Twenty-six per cent of the functional residual capacity and 29 per cent of

Summary: Restrictions of ventilation existed on the side of the lesion in all patients with bronchospirometric measurements. The total vital capacity was usually abnormally low and the unilateral vital capacity, where measured, was invariably low. The residual volume was also commonly reduced; it infrequently comprised a larger proportion of the total lung capacity than normal. No instance of impaired intrapulmonary mixing was found. No clear distinction could be made between patients on the basis of etiology.

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TABLE III. PRE- AND POSTOPERATIVE UNILATERAL AND BILATERAL TOTAL LUNG CAPACITIES IN 3 PATIENTS TREATED BY PULMONARY DECORTICATION

		PATIENT NO. 9		PATIENT NO. 8		PATIENT NO. 3	
		PREOP.	POSTOP.	PREOP.	POSTOP.	PREOP.	POSTOP.
Vital Capacity	Rt., c.c.	3033	2665	410	760	2492	2386
	Lt., c.c.	533	1089	1800	1560	721	685
	Sum, c.c.	3566	3754	2210	2320	3213	3071
	Bilat., c.c.	4115	4180	3310	3415	3331	3005
	Rt., %	85	71	19	33	78	78
	Lt., %	15	29	81	67	22	22
Residual Volume	Rt., c.c.	748	603	455	755	735	847
	Lt., c.c.	266	656	1115	1225	477	450
	Sum, c.c.	1014	1259	1570	1980	1212	1297
	Adj., c.c.	859					
	Bilat., c.c.	740	1321	1710	1885	1104	1360
	Rt., %	74	48	29	38	61	65
	Lt., %	26	52	71	62	39	35
Functional Residual Capacity	Rt., c.c.	1386	1225	580	1070	1310	1377
	Lt., c.c.	358	923	1685	1670	612	605
	Sum, c.c.	1744	2148	2265	2740	1922	1982
	Bilat., c.c.	1625	2121	2405	2635	1924	2070
	Rt., %	79	57	26	39	68	69
	Lt., %	21	43	74	61	32	31
Total Lung Capacity	Rt., c.c.	3781	3268	865	1515	3227	3233
	Lt., c.c.	799	1745	2915	2785	1198	1135
	Sum, c.c.	4580	5013	3780	4300	4425	4368
	Bilat., c.c.	4855	5501	5020	5300	4435	4365
	Rt., %	83	65	23	35	73	74
	Lt., %	17	35	77	65	27	26
$\left(\frac{\text{R.V.}}{\text{T.L.C.}}\right) \times 100$	Rt.	20	18	53	50	23	26
	Lt.	33	38	38	44	40	40
	Bilat.	15	24	34	36	25	31
$\left(\frac{\text{F.R.C.}}{\text{T.L.C.}}\right) \times 100$	Rt.	37	37	67	71	41	43
	Lt.	45	53	58	60	51	53
	Bilat.	33	39	48	50	43	47
Mixing Index	Rt., % N_2	0.91	0 87	6.77	2.67	cont.*	cont.*
	Lt., % N_2	1.10	1.34	1.32	1.82	2.32	4.80
	Bilat., % N_2	0.60	0.53	1.59	2.24	0.86	0.98

*Contaminated during collection. Normal index (2.5 per cent) used in computing F. R. C.

the residual volume were contributed by the right lung preoperatively; postoperatively these figures were increased to 39 and 38 per cent, respectively. The increase in the functional residual capacity of the affected side exceeded that in the inspiratory capacity, resulting in a higher ratio of the functional residual capacity to the total lung capacity postoperatively (71 as compared to 67, preoperatively). The residual volume increased in about the same proportion as the vital capacity so that the residual volume:total lung capacity ratio postoperatively was about the same as the ratio preoperatively (53 preoperatively, 50 postoperatively).

In contrast to this increase in all compartments of the lung volume in a patient with a satisfactory operative result are the figures for Patient 3 (Fig. 4) whose oxygen consumption and vital capacity suffered on the side of operation in consequence of surgery. In this patient, the functional residual capacity and residual volume showed essentially no change as a result of the operation. Inasmuch as the inspiratory capacity and expiratory reserve also did not change, volumetric ratios remained constant. The failure of the lung to expand more fully postoperatively therefore applied to all compartments of the total lung capacity.

Patient 9 is of further interest in that gross differences in the distribution of the various volumetric compartments existed postoperatively. Thus, although only 29 per cent of the vital capacity was contributed by the left lung, the proportion of the residual volume and the functional residual capacity was 52 per cent and 43 per cent, respectively. Accordingly, on the affected side the ratio of the residual volume to the total lung capacity and of the functional residual capacity to the total lung capacity were 38 per cent and 53 per cent, respectively, as compared to 18 per cent and 37 per cent contralaterally.

Gas Exchange (Table IV)

A. Blood Gas Contents and Ventilation Perfusion Relationships

1. *Effect of Constricting Pleural Peel.*—Oxyhemoglobin saturation of arterial blood below 94 per cent was found in only 1 of the 7 patients with preoperative determinations (No. 1, 91.9 per cent). Accordingly, none of the 3 patients with gradient studies demonstrated a substantially elevated venous admixture component at rest, the highest value being 9 per cent. The ratio of dead space volume to tidal volume was also normal in these 3 patients. There were no abnormalities in the carbon dioxide contents of arterial blood in the 7 patients with preoperative determinations. It is evident, therefore, that gross abnormalities in the blood gases or the relationship between alveolar ventilation and perfusion were not commonly found in the patients subjected to these analyses. The presence of marginal abnormalities however, was not unusual. In Patient 11, these were significantly increased by exercise (Table IV).

2. *Effect of Operation.*—The saturation of arterial blood was improved in all save 1 of the 6 patients with pre- and postoperative determinations. The single exception (No. 2) showed a decrease in saturation from 97.3 to 92.1 per cent. The 1 patient (No. 1) with a low preoperative value was normal postoperatively (97.7 per cent).

3. *Postoperative Status.*—In each of the 7 patients with postoperative studies, the saturation of the arterial blood was in excess of 92 per cent. The 5 patients with gradient studies had venous admixture ratios of 7 per cent or less; dead space values were also normal (less than 30 per cent of tidal volume) in these five instances.

Summary. The patients studied did not show striking deficiencies in blood gas content or abnormalities in ventilation perfusion relationships either pre- or postoperatively.

B. Diffusion

1. *Unilateral Participation in Oxygen Uptake (Table II).*—P operatively the affected side invariably was abnormally low in

TABLE IV. PRE- AND POSTOPERATIVE GAS EXCHANGE DATA IN EIGHT PATIENTS TREATED WITH PULMONARY DECORTICATION

		BASIC DATA												DERIVED VALUES						
PATIENT NUMBER	ACTIVITY	BP–47*	$F_{I_{O_2}}$	$F_{E_{CO_2}}$	$\dot{V}$	f	R	$P_{a_{CO_2}}$	$C_{a_{CO_2}}$	$P_{A_{O_2}}$	$P_{a_{O_2}}$	$S_{a_{O_2}}$	$\dot{V}_{O_2}$	DEAD SPACE			VENOUS ADMIXTURE	DIFFUSING CAPACITY		% O_2 UPTAKE AFFECTED SIDE
														V_{C_D}		V_{C_D}/V_T × 100 (<30)†	$\dot{Q}_{VA}/\dot{Q}_T$ × 100 (<6)†	TOTAL (68-86)†	M² (35-46)†	
														TOTAL C.C.	M² C.C.					
9	Preop Rest								51.57			95.9								18
	Exercise	711	.2093				.889	40	48.90	105	102	97.3					1			
	Exercise	711	.1306				.978	35	42.69	60	44	79.0	1806				1	65	32	
	Postop Rest	712	.2093	3.348	8.9	22.5	.840	44	51.36	99	84	95.0		106	52	27	7			16
	Exercise	712	.2093				.924	36	44.21	111	87	95.5					6			
	Exercise	712	.1261				1.132	33	36.96	59	42	77.0	2287				6	85	42	
11	Preop Rest	726	.2093	3.249	7.4	17.2	.770	43	49.44	98	84	94.8		120	67	28	7			7
	Exercise	726	.2093				.875	42	44.52	105	73	93.0					12			
	Exercise	726	.1279				1.058	33	35.75	62	37	70.0	1208				12	38	21	
	Postop Rest	721	.2093	3.729	6.9	17.7	.770	39	47.95	101	93	96.6		46	25	12	3			30
	Exercise	721	.2093				.812	37	34.20	106	81	94.5					8			
	Exercise	721	.1175				1.016	30	24.22	55	35	59.9	1470				8	54	30	
3	Preop Rest	713	.2093	3.487	5.8	13.7	.730	41	50.64	96	87	96.2		92	48	19	4			26
	Exercise	713	.2093				.880	41	44.14	103	87	95.5					7			
	Exercise	713	.1257				1.068	37	32.95	56	37	64.0	1758				7	65	34	
	Postop Rest	709	.2093						51.43			97.7								19
	Exercise	709	.2093				.921	46	43.01	107	86	95.0					6			
	Exercise	709	.1254				1.180	38	32.82	59	36	62.0	1626				6	54	28	
1	Preop Rest								44.77			91.9								
	Postop Rest	711	.2093	3.464	8.7	18.0	.850	43	48.29	100	93	97.7		131	68	27	3			26
6	Postop Rest	721	.2093	2.916	6.9	18.0	.820	40	50.00	104	86	95.0		108	71	28	8			24
7	Preop Rest								46.63			95.2								17
	Postop Rest	711	.2093	3.677	4.2	12.0	.850	45	50.98	97	91	96.9		72	35	23	2			40
5	Preop Rest	711	.2093	3.934	6.8	20.0	.900	40	49.99	105	85	95.7		27	16	8	9			24
2	Preop Rest								44.69			97.3								10
	Postop								49 89			92.1								36

*See text under "Methods" for explanations of abbreviations.
†Normal values.

uptake (below 40 per cent in patients with involvement on the right, below 30 per cent when the abnormality was on the left).

Seven of the 9 patients with pre- to postoperative comparisons showed increases on the affected side exceeding 10 per cent (mean 19 per cent, maximum 26 per cent, minimum 11 per cent). Oxygen uptake in 1 of the remaining 2 was not significantly changed (fall of 2 per cent, Patient 9) and the other (No. 3) suffered a reduction of 7 per cent.

Abnormally poor oxygen uptake on the side of operation persisted postoperatively in 9 of the 11 patients. In 6 of these (Nos. 1, 3, 6, 7, 8, and 10) the degree of abnormality was such that when the right lung was affected it contributed less than 40 per cent and where the left lung was affected its participation was less than 30 per cent. Two patients (No. 4 and No. 5) had a normal distribution of oxygen uptake postoperatively.

Summary: Pleural peels affected the ipsilateral lung adversely in all instances. Operation usually reduced the degree of abnormality significantly. In 9 of 11 patients, the restoration was incomplete.

2. The Maximum Diffusing Capacity (Table IV).—This measurement was performed preoperatively in 2 patients with moderate reduction of unilateral oxygen uptake (No. 3, 26 per cent—Fig. 4; No. 9, 18 per cent) and in 1 in whom this deficiency was severe (No. 11, 7 per cent—Fig. 2). In the former 2 the maximum diffusing capacity with exercise was minimally reduced (No. 3, 65; No. 9, 65), whereas in the latter this measurement revealed a considerable abnormality (No. 11, 38). The effects of operation as determined by this measurement were different in each instance. In Patient 3, whose unilateral contribution to oxygen uptake was reduced from 26 per cent preoperatively to 19 per cent postoperatively, the maximum diffusing capacity fell from 65 to 54 (Fig. 4 *B*). The unilateral contribution to oxygen uptake for the second patient (No. 9) was virtually unaffected by the operation; the maximum diffusing capacity, however, increased from 65 to 85. The third patient (No. 11) was considerably improved by operation (preoperative oxygen uptake on affected side, 7 per cent; postoperative, 30 per cent); accordingly, the maximum diffusing capacity increased from 38 to 54 (Figs. 2*B*). With respect to postoperative status, only the value for Patient 9 is normal, the other 2 being low. As is indicated in the discussion, the normal value is subject to question.

DISCUSSION

Factors Affecting Operative Results.—It is evident from comparing the effects of a pleural peel or the results of operation in selected instances that considerations other than etiology are the determinants of pre- and postoperative respiratory status. In the absence of extensive *parenchymal damage,* a lung which contributes negligibly to respiration preoperatively may show striking improvement postoperatively whether it be incarcerated by a tuberculous or a nontuberculous process (see Patients 2, Fig. 1, and 11, Fig. 2).

To the extent that the decorticated lung has been destroyed by disease, the postoperative status is understandably jeopardized (Patients 6 and 8, Fig. 3). Inasmuch as such irreversible damage is more common [illegible]

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BASIC DATA														DERIVED VALUES						
														DEAD SPACE			VENOUS ADMIXTURE	DIFFUSING CAPACITY		
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PATIENT NUMBER	ACTIVITY	BP–47*	$F_{I_{O_2}}$	$F_{E_{CO_2}}$	$\dot{V}$	f	R	Pa_{CO_2}	Ca_{CO_2}	$P_{A_{O_2}}$	Pa_{O_2}	Sa_{O_2}	$\dot{V}_{O_2}$	TOTAL C.C.	M² C.C.	$V_{C_D}/V_T \times 100$ (<30)†	$\dot{Q}_{VA}/\dot{Q}_T \times 100$ (<6)†	TOTAL (68-86)†	M² (35-46)†	% O_2 UPTAKE AFFECTED SIDE
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2	Preop Rest								44.69			97.3								10
	Postop								49.89			92.1								36

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DISCUSSION

Factors Affecting Operative Results—It is evident from comparing the effects of a pleural peel or the results of operation in selected instances that considerations other than etiology are the determinants of pre and postoperative respiratory status In the absence of extensive *parenchymal damage*, a lung which contributes negligibly to respiration preoperatively may show striking improvement postoperatively whether it be incarcerated by a tuberculous or a nontuberculous process (see Patients 2, Fig 1, and 11, Fig 2)

To the extent that the decorticated lung has been destroyed by disease, the postoperative status is understandably jeopardized (Patients 6 and 8, Fig 3) Inasmuch as such irreversible damage is more commonly associated with tuberculous pleural involvement than it is with the other conditions for which decortication is performed, results in tuberculous patients unselected for the absence of parenchymal involvement can be expected to be relatively poor.[5] It should be observed, however, that the limitation in recovery for patients receiving early treatment is imposed by the presence of pulmonary pathology rather than by the etiology of the pleural peel. Although this point has been clearly made by studies of patients other than ours,[3] previous implications to the contrary[4, 5] may justify its re-emphasis.

The *duration of incarceration* is another of the factors which affect the degree of functional improvement.[4] The limited change found in Patient 8 (Fig. 3), contrasting with the conspicuous restoration in Patients 5 and 11 (Fig. 2), is probably partly attributable to the length of time during which the affected lung's activity was restricted. The adverse effect of time is perhaps less surprising, however, than is the fact that improvement of the magnitude recorded is possible after seven years of restriction (Patient 8, Fig. 3). Indeed, even longer periods have been shown to be compatible with significant recovery.[3] It should be pointed out that preoperative appraisal is particularly important in these patients, for in its absence the degree of postoperative abnormality might obscure the value of operation.

The adverse effect of *operative complications* is illustrated by a comparison of the figures for Patients 1 and 2 (Table II) both of whom had a nontuberculous pleural membrane on the left. Inadvertent left phrenic nerve paralysis and a postoperative empyema in the former doubtless account for the relatively low postoperative values recorded. Similarly, the postoperative bronchospirometric differences between Patients 10 and 11, both of whom had comparable preoperative deficits due to tuberculous empyema, are in all likelihood attributable to a postoperative bronchopleural fistula in the former.

Among the additional considerations which must be weighed in anticipating the functional change as well as the postoperative result is the patient's *preoperative status.* Obviously a patient with normal function preoperatively cannot be expected to improve and, correspondingly, one with extremely poor function can hardly be adversely affected. Among the 11 patients, 7 were comparable with respect to age, sex, minimal or no parenchymal involvement, duration of disease (less than one year), and absence of serious postoperative complication. Among these, improvement in vital capacity or maximum breathing capacity was usually not found unless these modalities were depressed below 70 per cent of normal preoperatively.

Selected Observations.—Among the most constant effects of pulmonary decortication in these 11 patients was an increase in residual volume, a change which could be attributed to the removal of a noncommunicating intrathoracic mass and to the release of retracted parietes. Associated roentgenographic findings were the elimination of density between the lung and thoracic wall and the widening of the intercostal spaces which was frequently seen postoperatively. This increase in residual volume, either absolute or relative to the total lung capacity, should not be identified with "overdistention" and construed as detrimental to function. Patient 7, for example, demonstrated an increase in oxygen uptake on the affected side from 17 per cent preoperatively to 40 per cent postoperatively although his residual volume almost tripled and the volumetric ratio became abnormal (40 per cent). So long as it is not assumed that the increase in residual volume is out of proportion to the additional number of inflated alveoli, there is reason to interpret the change as favorable rather than the opposite.

The functional residual capacity was also commonly augmented by operation, an increase exceeding 200 c.c. having occurred in 7 of the 11 patients. The reasons for this increase parallel those cited for the changes in residual volume.

In reconstructing the corollaries of these volumetric increases in a patient such as No. 11 (Table II, Fig. *2B*), it is reasonable to assume that a portion, if not most, of the additional air contained by the lung fills alveoli which were previously collapsed. In the present study and in that of Carroll[1] the figures for physiologic dead space and for venous admixture both pre- and postoperatively suggest that normal relationships between ventilation and perfusion are approximated in compressed as well as in re-expanded parenchyma, areas which are unventilated preoperatively tend also to be unperfused and those that are ventilated are correspondingly perfused. As alveoli open postoperatively, the restoration of their ventilation tends to be matched by perfusion of their capillaries with blood. Expansion of the alveolar capillary bed is the structural result, the functional counterparts being a relative increase in the contribution of the affected lung to oxygen uptake and an augmented diffusing capacity.

Although these latter two indices differ in precision and to some extent in implication, they are nevertheless both functions of the expansiveness of the alveolar capillary bed.[13] Accordingly a change in one was associated in 2 patients (No. 3, Fig. *4B* and No. 11, Fig. *2B*) with a change of similar sign in the other.

In the third patient subjected to both analyses pre- and postoperatively, unilateral uptake of oxygen was not significantly affected by surgery (preop. 18 per cent, postop. 16 per cent). Diffusing capacity, however, increased from 65 preoperatively to 85 postoperatively. A difference of this magnitude might be explained by summating the maximum errors of the analyses required for measuring the diffusing capacity.[12] Indeed, the fact that the postoperative figure is normal, although the participation of the left lung in oxygen uptake is so low, suggests that estimation of the diffusing capacity, bronchospirometric determinations, or both, were in error. An alternative explanation, assuming the reliability of both figures, is that the exercise required for the maximum diffusing capacity determination brought out properties of the lung not detectable in the "resting" state. Exercise is known to result in expansion of the diffusing surface.[12] It is conceivable that exercise increased the effective diffusing surface postoperatively in spite of the fact that the relative dimensions on the right and left at rest remained unaltered.

Despite improvement, no patient was fully restored to normal by operation. The short postoperative interval elapsing before the second study probably accounts in part for this limited recovery. Patients studied within three following even a minimal resection commonly show a loss in vital capacity and maximum breathing capacity amounting to 12 per cent of their preoperative value.[17] Wright and his associates[1] and Patton and his co-workers[2] have shown that unilateral return of function following decortication is protracted, in some instances extending over a period exceeding one year. With these considerations in mind, it is evident that the extent of improvement in the present patients was probably less than may be expected ultimately. By the same token, the minimally adverse effects on some tests in Patients 3, 4, 6, and 9 would possibly not have been found after a longer convalescence. In no instance was there evidence, as reported in some patients with extensive parenchymal damage,[1] that the respiratory status postoperatively included gross abnormalities which had not been present preoperatively.

Attention has been drawn[4] to the number of patients in whom contribution of the decorticated lung to oxygen consumption is less than that to ventilation and a pathologic basis for this finding in tuberculosis has been suggested. This disproportion was found in 5 of the 11 patients. Each of these had either parenchymal damage (No. 6, No. 8), a postoperative complication (No. 1), or a poor functional result in terms of unilateral oxygen uptake (No. 3 and No. 9). In none of the other 6 patients, 4 of whom had tuberculous pleural disease (Nos. 5, 7, 10, and 11), did this finding prevail. When parenchymal damage was minimal or absent and when operation was early and uncomplicated, therefore, proportionate participation in ventilation and oxygen consumption was the rule rather than the exception. If one uses oxygen uptake as a criterion of perfusion, it is apparent that this generalization follows from the fact that the postoperative values for ventilation-perfusion relationships fell within normal limits.

SUMMARY

Eleven patients requiring pleural decortication of either a tuberculous or a nontuberculous pleural peel were evaluated from a respiratory point of view both pre- and postoperatively. The tests pertained to unilateral and bilateral ventilation and total lung volumes, intrapulmonary mixing of respiratory gases, ventilation-perfusion relationships, and relative dimensions of the diffusing surface (maximum diffusing capacity).

The preoperative deficit usually consisted of impaired ventilation, diminished lung volumes, and a reduction in the dimensions of the alveolar capillary bed. Defects in the mixing of gases within the lung and in the relationship between ventilation and perfusion were uncommon.

Operation was usually followed by improved ventilation, increased lung volumes, and restoration of alveolar-capillary units. Etiology per se did not affect the magnitude of these changes. Duration of disease, parenchymal involvement, postoperative complications, and the degree of preoperative functional impairment were factors contributing to the extent of recovery. Protracted disease did not preclude improvement.

Postoperatively, no patient was normal with respect to all tests, possibly because the convalescence prior to re-evaluation was brief. No gross deficit occurred as the direct result of surgery.

Consistent with the essentially mechanical nature of the impairment imposed on the lung by pleural envelopment, the physiologic abnormalities produced were reversible to varying degrees by surgical removal of the confining structures

Gas analyses and studies of bilateral ventilation and lung volumes were performed by Hospital Corpsmen of the United States Navy trained in the Cardiopulmonary Laboratory of the U S Naval Hospital, St Albans The authors are particularly grateful for the diligence of the following Jerry Borrelli, John Briggs, Kenneth Gorr, Henry Haddad, James Heid, Roy Johanessen, Joseph Malin, Richard Monsees, John O'Brien, Robert Obser, Ernest Picknally, David Prior, and Robert Rauf

The authors are also indebted to Dr John Cincotti, Chief of Surgery at the Veterans Administration Hospital, Brooklyn, New York, for referring Patient 8

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COMPLICATIONS OF FIRST RIB FRACTURE, INCLUDING ONE CASE EACH OF TRACHEOESOPHAGEAL FISTULA AND AORTIC ARCH ANEURYSM

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SURVEY OF LITERATURE: INCIDENCE AND COMPLICATIONS

FRACTURE of the first rib has become an increasingly frequent injury since the advent of the modern automative age. Despite its sturdy structure and relatively protected situation, the first rib is vulnerable to sufficient degrees of indirect violence such as that supplied by the "steering wheel" chest injury, or from direct violence of various types. According to Johnston,[1] who reported an early case of first rib fracture complicated by lung abscess, these principles were emphasized more than sixty years ago by Lane,[2] who postulated three mechanisms by which the first ribs were liable to fracture: (1) indirect violence transmitted through the clavicle, (2) direct violence from force applied from behind, and (3) indirect force transmitted through the sternal manubrium.

The earliest available record of traumatic first rib fracture was that by Jones,[3] 1869, whose patient was injured in a street fight. Apparently the first recorded case due to automobile accident was that of Codd,[4] in 1916. Neither of these patients had significant associated injury or complication.

Several recent series attest the increasing frequency of first rib fracture. Hinton and Steiner,[5] in 1940, described it in 14 of 393 right, and 8 of 414 left fractured ribs. Knoepp,[6] 1941, found 16 fractures of the right first rib, and 15 of the left, in a total of 386 cases of rib fracture. Powell[7] discovered 25 cases in the British Army during a nine-month period in 1950, not due to combat injuries. Huber,[8] however, was able to find only 26 cases in the world literature prior to 1934, to which he added 4 personal cases. Huber emphasized the difficulty of diagnosis of the uncomplicated case by x-ray, especially in instances in which other fractured ribs, more readily recognized, might explain the symptoms presented. That such a fracture may occasionally heal unrecognized is indicated in the reports of Cohen,[9] and Alderson,[10] who discovered healed, previously undiagnosed, isolated fractures of a first rib in approximately 0.1 per cent of routine chest x-ray in a combined series of more than 80,000 young military personnel. In 10 of Alderson's 73 cases, the fracture had been bilateral.

A variety of complications have been attributed to fractures of the first rib, but in most instances these have been the usual complications accompanying

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the fracture of any rib. Breslin,[11] in 1937, listed these complications of first rib fracture: (1) abscess formation, above or below the clavicle, (2) rupture of the apex of the lung, (3) empyema, (4) pleurisy, (5) hemorrhage, and (6) nerve symptoms, immediate, or delayed, due to pressure of callus. Ostrowski[1] described a ruptured subclavian artery resulting from fracture of the right first rib. Paralysis of the brachial plexus accompanying such injury has been described by Milligan and Ford,[13] and by Chavany, LeRoy, and Lobel.[14] Horner's syndrome caused by fracture of first rib was reported by Rebhorn,[15] and by Kulowski and Ryan.[16] Massive cervical subcutaneous emphysema occurred in 1 case of Huber's series.[8] Zimmerman[17] described a hematoma occupying the superior and middle mediastina following severe lateral chest compression which had resulted in fracture of the first and second ribs bilaterally, the left clavicle and right scapula. The hematoma resorbed spontaneously without sequelae.

ANALYSIS OF EIGHT YEARS' EXPERIENCE WITH REPORT OF TWO CASES

The occurrence of severe mediastinal complications in 2 patients suffering first rib fracture prompted a survey of our experience with this entity at this large veterans hospital. From Jan. 1, 1947, through Dec. 31, 1954, 170 patients were hospitalized with a diagnosis of fractured ribs, many associated with other injuries. Of this number, 17 (10 per cent) had fractures of one or both first ribs, isolated, or in addition to other rib fractures. These cases are briefly summarized in Table I. One patient, whose fracture was produced by a shotgun wound, has been omitted from the series. All the remainder had closed chest trauma.

It is readily apparent that in 2 patients (Case 10 and Case 16, Table I) there were significant complications involving mediastinal structures which could reasonably be attributed to the mechanisms responsible for fracture of the upper ribs. These cases will be considered individually.

As would be expected, the incidence of brachial plexus injury in this group (3 cases) was much higher than in the rib fracture series at large, especially since there was ipsilateral fracture of the clavicle in one of these.

It is interesting that there were 15 cases of second rib fracture, including one of bilateral occurrence, other than those accompanying fracture of a first rib, and of this group only one, which was associated with an ipsilateral clavicular fracture, showed evidence of brachial plexus injury. There were no mediastinal complications in this group, or in the remainder of the rib fracture series, the complications being confined to the usual effects of pleural puncture by the bone fragments: pneumothorax, hemothorax, subcutaneous emphysema, pneumonitis, and empyema, in order of frequency named.

Case 1 (Table I) was unusual in that a Horner's syndrome occurred on the right, where no rib cephalad to the fourth was fractured, while there was no evidence of associated lesion in the vicinity of the fractured left first rib. The other patient in the series exhibiting injury to the stellate ganglion (Case 12, Table I) had suffered fracture of the rigl
the right clavicle

TABLE I. CASES WITH FIRST RIB FRACTURE*

CASE NUMBER	PATIENT	AGE	HOW INJURED	RIBS FRACTURED	ASSOCIATED INJURIES	COMPLICATIONS	TREATMENT	REMARKS
1	R. N. U.	25	Auto accident	L 1 R 4-8	Fract. rt. scapula	Horner's syndrome, right	Symptomatic	No sequelae; 3-year follow-up
2	L. F. G.	37	Auto accident	L 2-4 R 1-5	Fract. pelvis	Right hemothorax; Right brachial plexus injury (Ulnar Dist.); Emphysema trunk and neck	Thoracenteses; Symptomatic	Well after 4 months; nerve injury transitory
3	K. B. W.	22	Auto accident	L 1	--	--	None required	No follow-up
4	F. R.	34	Auto accident	L 1, 2	Fract. facial bones; Fract. left scapula; Cerebral concussion	--	Orthopedic	5-year follow-up; chest negative
5	L. C.	26	Auto accident	R 1, 2, 4	Laceration, face	Contusion lung (hemoptysis); Right brachial plexus inj.	Symptomatic	Well after 3 weeks
6	L. W.	62	Auto accident	L 1, 5-9 R 1-10	Fract. vert. T 12, L 1-4; Fract. skull; Laceration, liver	Hemothorax, bilateral	--	Expired on admission
7	R. L. M.	44	Auto accident	R 1	Fract. femur, tibia	--	Orthopedic	Well after 3 months
8	T. C. M.	38	Auto accident	L 1, 3, 5 R 2-5	Fract. radius	Right pneumothorax (partial)	--	Refused treatment; chest neg. 1 year later
9	J. H.	57	No history	L 1 R 1	--	Bilat. obst. subclavian veins by callus	--	Admitted in heart failure; fractures discovered at autopsy

10	[illegible]	[illegible]	[illegible]	L 1	--	Diverticulum esophagus with tracheo esoph fistula	Repair of divert and fistula	3 month follow up, no recurrence
11	J R	29	Auto accident	L 1 3 R 5 7	Fract humerus, bilat , Rt sternoclavic separation, Cerebral concussion	--	Orthopedic	2 year follow up, chest negative
12	C L K	[illegible]	Auto accident	L 2 R 1, 2	Fract rt clavicle	Rt brachial plexus injury Horner's syndrome, right	Symptomatic	Well after 1 month, nerve lesions transitory
13	W H B	35	Auto accident	R 1	Fract acetabulum Compound fract tibia	--	Symptomatic	6 month follow up, chest negative
14	H H W	10	Crushed by lumber stacker	R 1 8	--	Hemothorax Pneumothorax	Thoracenteses, Transfusions	2 year follow up, chest negative
15	J A R	12	Auto accident	R 1	Fract vert C 2 6, 7	--	Orthopedic	2 year follow up, chest neg , no neurological sequelae
16	H P M	21	Auto accident	L 1, 2	Fract tibia and fibula	Aneurysm, aortic arch	Aneurysm wrapped with reactive polyethylene	6 month follow up, aneurysm slightly smaller, no referable complaints

* All patients are men Those with two initials are Negro

The unusual effect of fracture healing in Case 9 (Table I) is thought to be of sufficient interest to warrant brief description. A 57-year-old Negro man was hospitalized in a state of cardiac failure. He had a long history of syphilitic and hypertensive cardiovascular disease, with multiple admissions to this institution. No history of trauma was given. An unusual feature was marked edema of both upper arms, which was out of proportion to ankle edema and other manifestations of right heart failure. The patient followed a rapidly deteriorating course, and died on the eighth hospital day. At autopsy, recent fractures of the first ribs bilaterally, 5 cm. from the costosternal junctions, were found. Callus about the healing fractures measured 4 cm. in diameter, compressing the subclavian veins against the clavicles at those points. This, in the pathologist's opinion, was sufficient to produce the marked edema of the upper arms.

CASE REPORT

The patient, C. D. T. (Case 10, Table I), was a 24-year-old white man who was first admitted to the Veterans Administration Hospital, Jackson, Miss. on July 4, 1952, one week following an automobile accident in which he suffered a ''steering wheel injury'' to the chest. He had no significant complaints until four days following the accident, when he developed a sore throat, had difficulty in swallowing, and regurgitated a piece of meat eaten the previous day. There was evidence of acute pharyngitis, which responded to antibiotic therapy. The chest was clear, and x-rays reportedly negative for rib fracture. His symptoms improved sufficiently so that he was discharged on July 23, 1952.

One month after discharge the patient returned to the Outpatient Department complaining of an intermittent dry cough. X-ray on that date revealed a healing fracture of the left first rib. Examination was otherwise negative.

He continued to cough intermittently, and noted that swallowing liquids frequently resulted in coughing and gagging, while he had no difficulty in swallowing solid foods. The sputum became purulent, occasionally blood streaked, and he developed a low-grade fever. He was readmitted to the medical service on Nov. 7, 1952, with the diagnosis of lung abscess, left upper lobe, thought to be due to material aspirated at the time of the injury, or during the episode of pharyngitis.

The abscess was evacuated spontaneously, and entirely disappeared on conservative management during one month of hospitalization. Bronchoscopy during this admission revealed only congestion of the mucosa of the left main bronchus.

Ten days following discharge, the patient was again admitted to the medical service, with evidence of pneumonitis, lower lobe, right lung. Again there was rapid response to antibiotics. However, in view of the recurring respiratory difficulties, and the continued complaint of cough induced by swallowing liquids, surgical consultation was obtained.

An esophagram on Jan. 2, 1953, revealed an anterior esophageal diverticulum of the pulsion type at the level of the fourth thoracic vertebra (Fig. 1). There was no sign of barium entering the trachea, however it was noted fluoroscopically that the filled diverticulum impinged upon the trachea, producing coughing and gagging. Bronchoscopy was repeated, revealing an erythematous papule, 6 mm. in diameter, on the posterior tracheal wall just above the bifurcation. A droplet of mucus exuded from the center of this lesion during observation, and was assumed to have passed through a fistula originating from the esophageal diverticulum. No additional information was obtained from esophagoscopy.

Thoracotomy was performed on Feb. 4, 1953, through the right fourth intercostal space. There was a diverticulum of the esophagus, approximately 2 cm. in diameter, situated 4 cm. above the level of the azygos vein. It arose from the anterior surface, and was intimately attached to the posterior wall of the trachea (Fig. 2*A*). There was considerable fibrosis and edema of tissue surrounding the diverticulum. The diverticulum, which measured 4 cm. in length, was freed of surrounding tissues and divided at its mid-point between two small bronchial clamps Each stump was closed with two rows of interrupted No 3 0 silk mattress sutures, so spaced as to obliterate the diverticulum, and thus the fistula, at both ends (Fig 2*B*) The thorax was closed in routine fashion, with water seal drainage

The postoperative course was uneventful The patient was fed by gastric tube for five days, and was allowed a soft diet on the tenth day He was discharged on Feb 16, 1953, with no complaint In answer to a letter on April 27, 1953, the patient stated that he had remained symptom free Following this, he was unfortunately lost to follow up

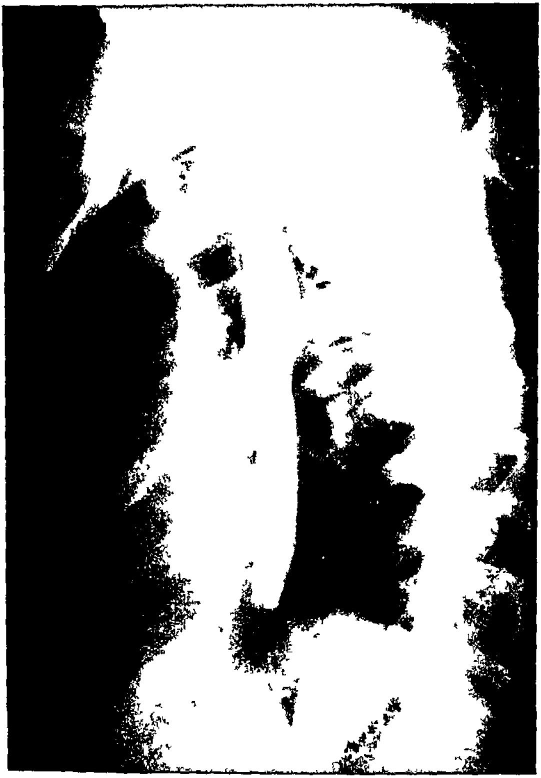
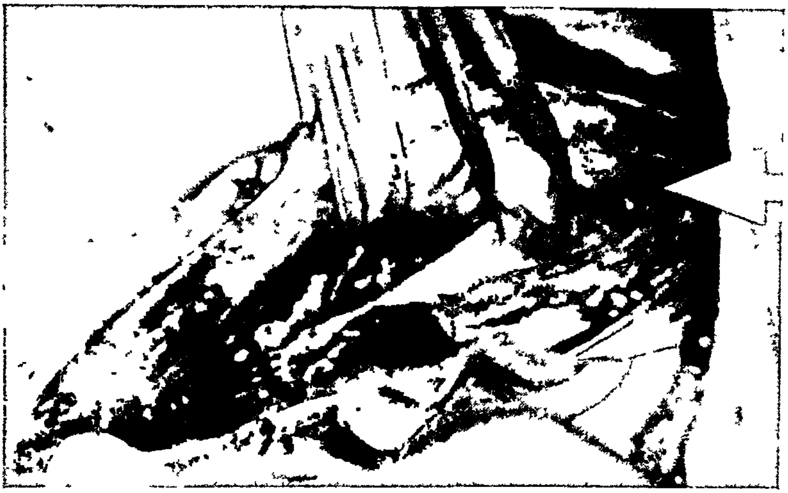


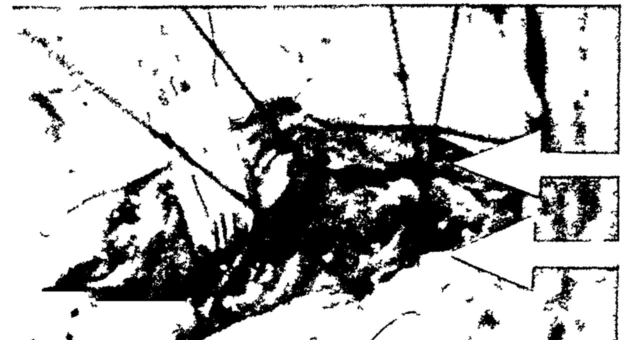
Fig 1—Case 10 Table I Esophagram which reveals a pulsion diverticulum on the anterior wall of the esophagus No barium entered the diverticulotracheal fistula

To summarize, an esophageal diverticulum, with fistulization into the trachea, was diagnosed and repaired six months following an automobile accident which had resulted in fracture of the left first rib Symptoms present during the intervening period strongly suggest that the diverticulum, as well as the tracheoesophageal fistula, was traumatically incurred It is possible, however, that an asymptomatic congenital diverticulum had existed previously, and that traumatic fistulization occurred between the trachea and this weak point of the esophageal wall

Comment.—An excellent review of tracheoesophageal fistula resulting from closed chest trauma has been recently presented by Volk, Storey, and Marragoni,[18] who found 7 previous cases,[19 25] and reported a personal case which was unique in that it involved the cervical trachea and esophagus, and was the first reported case due to blast injury. In none of these instances did fracture of a first rib occur, however, Piquet, Muller, and Marchand[20] described fracture of left ribs 3, 4, and 5, and the patient of Stephens and Ferrier[23] suffered a fracture of the left scapula.



A.



B

Fig 2, *A* and *B*—Case 10, Table I *A*, Diverticulum of anterior esophageal wall, the fundus intimately adherent to the posterior tracheal wall, where a small traumatic fistula had developed The esophagus is retracted posteriorly by a rubber drain The arrow points to the fistula which is retracted by a linen tape *B*, The diverticulum divided, each stump obliterated with double rows of interrupted silk sutures Arrows indicate suture lines

Six of these patients[18, 21 25] were treated by definitive surgery with good results Five authors[21 25] used the right thoracotomy approach originally employed by Adams and Mabley.[21] Volk, Storey, and Marragoni[18] used a left anterior cervical approach to repair the fistula they reported, which lay at the level of the thyroid isthmus

In the case of Piquet, Muller, and Marchand,[20] there was an esophageal diverticulum at the site of the fistula, similar to the situation just described. The diverticulum, however, was thought to have been pre-existing, rather than a product of the trauma which was responsible for the fistula. No other such combination has been reported, although Jenkinson and Bate,[26] and Coleman and Bunch[27] reported fistulas between esophageal diverticula and the tracheobronchial tree from causes other than trauma.

Apparently, then, this case represents the ninth reported instance of *tracheoesophageal fistula* resulting from closed trauma to the chest, and the first to be associated with a fracture of a first rib. It is the seventh such fistula to be successfully repaired by direct division and suture.

CASE REPORT

The patient, H. F. M. (Case 16, Table I), was a 24 year old white man who was admitted to the Veterans Administration Hospital, Jackson, Miss in October, 1952, following an automobile accident in which he suffered simple fracture of the right tibia and fibula, in addition to fractures of the left first and second ribs Chest x ray revealed a widening of the superior mediastinum in the posteroanterior view (Fig. 3), interpreted as hematoma and/or mediastinitis, secondary to the chest trauma There were no referable complaints, or signs of mediastinal involvement The extremity fractures were treated on the orthopedic service with open reduction, the hospital course being complicated only by the development of a mild left pneumonitis with pleural effusion, which responded to conservative management. On subsequent orthopedic observations in December, 1952, March, 1953, and May, 1953, there was no symptom or sign referable to the chest, the mediastinal shadow remaining unchanged by x ray.

In December, 1954, the patient applied for re enlistment in the Marine Corps Chest x ray revealed a mass in the vicinity of the aortic arch He was disqualified for enlistment, and hospitalized for appropriate studies to determine the nature of the lesion There had been no complaints referable to the chest or cardiovascular system The patient had been employed as a ward attendant in a mental institution for six months prior to admission, with no limitation of activity.

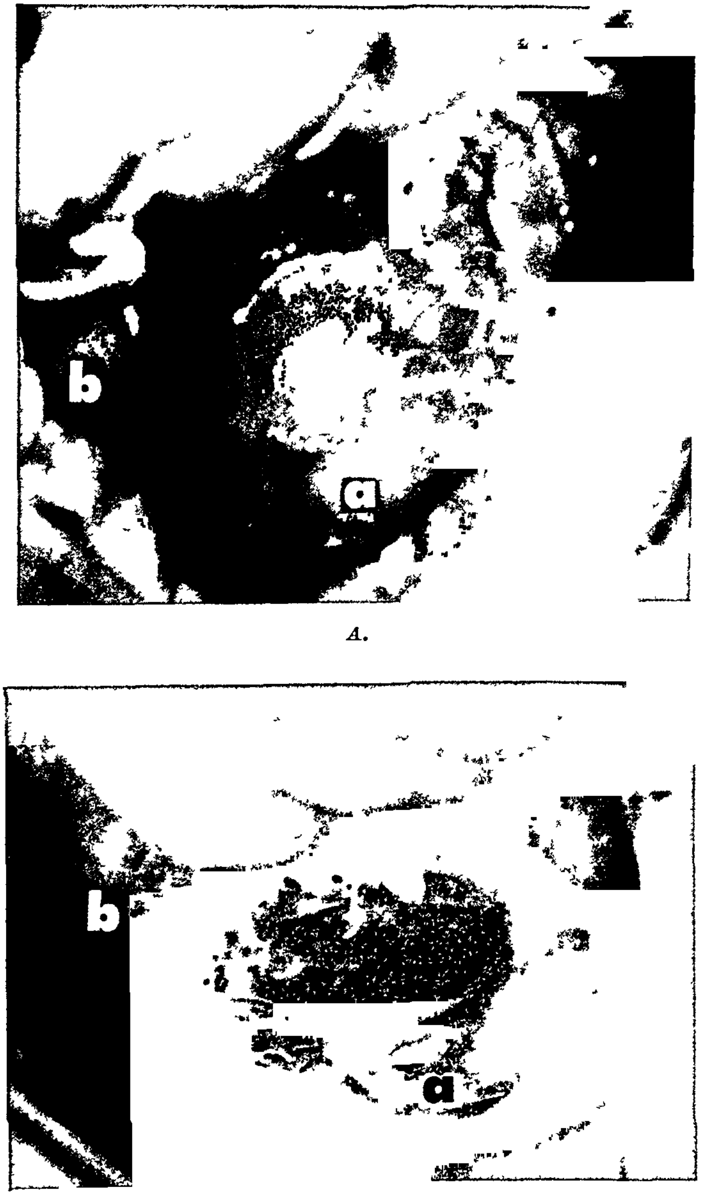
Past history, in addition to the injuries described, included multiple skull fractures incurred in a fight in November, 1951, following which the patient had developed grand mal epilepsy Fractures of maxilla and ilium were sustained in an automobile accident in April, 1952 Following each injury, chest x rays at this institution had been normal. There had been no epileptic seizure for eight months prior to the last admission.

On admission, Dec 28, 1954, there were no abnormal physical signs Blood pressure was 110/72, both arms The chest was clear, with no palpable thrill, bruit, or murmurs Chest x ray revealed a mass which appeared to project into the left lung field above the hilar region, with a suggestion of fine calcium deposits in its periphery. On fluoroscopy, the mass could not be dissociated from the aortic shadow, and it displayed an expansile type of pulsation. An angiocardiogram on Jan 3, 1955, confirmed the impression of aneurysm of the descending portion of the aortic arch (Fig. 4, *A* and *B*) Routine laboratory studies, including sputum examination and tuberculin tests, were negative Bronchoscopy was normal but for a suggestion of increased carinal pulsation Left scalene fat pad biopsy, requested by the chest therapy board, was negative for neoplasm

Thoracotomy was performed on Jan 11, 1955, through a sternal splitting incision extending into the left third intercostal space. An aneurysm measuring 6 by 8 cm on its predominant

The patient was discharged on Feb. 18, 1955, to remain at limited activity. He was seen on April 20, 1955, at which time he had no complaints. Blood pressure was 118/76 both arms, the chest was clear. A posteroanterior chest film on that date revealed slight diminution in size of the aneurysm (Fig. 6). He was personally contacted on May 29, 1955, and again had no complaints.

To summarize, a *traumatic fusiform aneurysm* involving the distal portion of the aortic arch was diagnosed more than two years following an autombile accident which had resulted



A.

B.

Fig. 5, *A* and *B*—Case 16, Table I *A*, Traumatic aneurysm of thoracic aorta, involving distal half of arch. The left subclavian artery arose from the proximal portion of the aneurysm, and the left vagus and phrenic nerves were embedded along its anterior surface. Calcium plaques may be seen in the most prominent area. Aortic aneurysm is marked by "a," and descending aorta by "b." *B*, Aneurysm covered with irritative polyethylene, with outer layer of nonirritating polyethylene, both sheets sutured to mediastinal pleura about all surfaces of the aneurysm The aortic aneurysm is marked "a," and descending aorta is just below "b" in fracture of the left first and second ribs Some widening of the superior mediastinum detectable by x ray shortly following the accident, and attributed to hemorrhage and/or mediastinitis, may have been, in retrospect, an important clue to the extent of trauma to the aortic arch The aneurysm, which was entirely asymptomatic, was covered with reactive polyethylene On early follow up, it has responded well to this conservative surgical attack

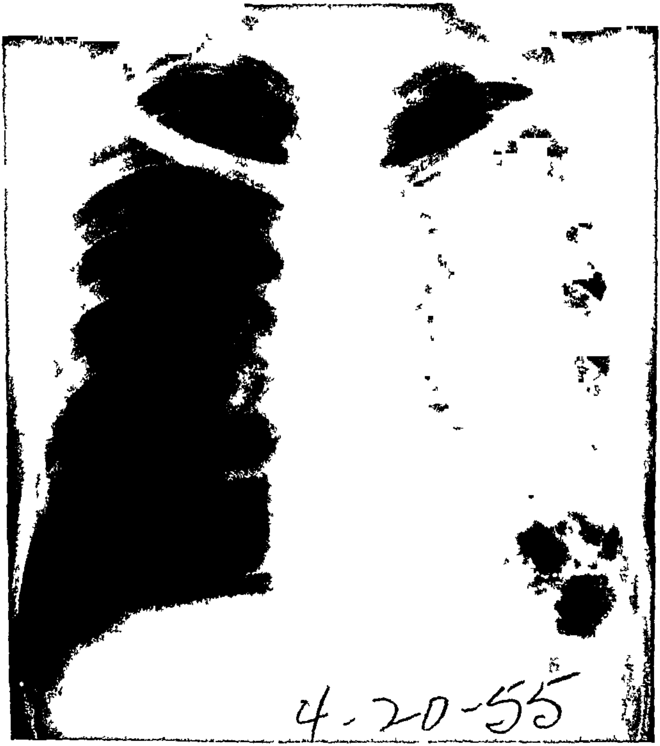


Fig 6 —Case 16 Table I Posteroanterior view of chest made three months after covering aortic arch aneurysm with reactive polyethylene The mass is slightly smaller than in the preoperative film (Fig 4A) Note persistent elevation of the left hemidiaphragm apparently from irritation of phrenic nerve

Comment —The mechanical factors culminating in aneurysm of the thoracic aorta secondary to indirect trauma have been well conceived Shennan[28] theorized that such aneurysms should occur at three sites (1) just above the aortic valve, (2) just below the attachment of the ductus arteriosus, and (3) at the origin of intercostal arteries These postulates were influenced by the work of Oppenheim,[29] who produced intimal rupture in cadavers' aortas at Shennan's sites 1 and 2 by injecting fluid at high pressure (3,000 mm Hg) The left subclavian artery as a result of an automobile accident in which she suffered fracture of the third ribs bilaterally, and the body of the first lumbar vertebra. The aneurysm was wrapped with reactive cellophane nine months following injury. Symptoms recurred one year postoperatively, accompanied by clinical and x-ray evidence of enlargement of the aortic shadow. The lesion was excised tangentially fifteen months following the first procedure, two years following injury, with good result.

Resection of traumatic aneurysms of the aortic arch and replacement by homografts have been successfully accomplished on two occasions. Stranahan, Alley, Sewell, and Kausel[49] report the case of a 25-year-old Negro man with a "classical traumatic aneurysm of the descending aorta" discovered by routine x-ray five years following an automobile accident of the steering wheel type. Multiple fractures of the skull and extremities, and contusions of chest and abdomen had occurred, though no fractures of rib, sternum, or clavicle were found.

Being unable to excise the aneurysm tangentially, which arose just below the left subclavian artery and encircled three-fourths of the aorta's circumference, Stranahan and his team excluded the distal aortic arch by means of an ingeniously devised shunt of Tygon, polyethylene, and silicone glass, which delivered blood from the subclavian artery into the aorta distal to the aneurysm. The aortic segment containing the aneurysm was resected, and replaced with an 8 cm. length of homologous freeze-dried aorta. On five-month follow-up the patient was doing well. These authors had previously employed a similar device in resecting a massive syphilitic aneurysm involving the entire thoracic aorta. In that instance, however, the shunt was somewhat more complex in that it delivered blood from the ascending aorta into both the innominate artery and the distal aorta.

Cooley and DeBakey[50] reported a successful resection of a traumatic aneurysm of the distal aortic arch in a 31-year-old man, which had recurred five months following partial tangential aneurysmectomy. This was 1 of 7 cases in which these authors have resected aneurysms of the distal arch and descending thoracic aorta, with replacement by homologous graft. In these cases, and in 5 patients in whom coarctations of the thoracic aorta were similarly resected and grafted, they have been able to cross-clamp the aorta distal to the left common carotid artery, without the aid of shunt, with a mortality rate of 16.7 per cent. They advocate the use of moderate hypothermia, especially in poor risk patients, and attempt to avoid occlusion of the aorta for periods in excess of one hour.

Our patient, then, is the second reported case of aneurysm of the aortic arch due to closed trauma, associated with a fracture of a first rib,[26] and the third in which fracture of any rib is reported.[46] The 2 patients with fractured sterna,[41, 45] as well as that of Weisel[43] with fracture of the left clavicle, however, would seem to reflect similar etiological factors. It is possible, of course, that in other reported cases rib fracture was overlooked, or not mentioned, though actually present.

From the few available reports of surgeons who have had the opportunity to treat such lesions, it appears obvious that the aneurysm, if saccular in type, should, if possible, be resected tangentially and the resulting defect repaired with preservation of aortic continuity during the procedure. Fusiform aneurysms, or those involving one half or more of the aorta's circumferences, should ideally be resected and replaced by homologous, or other, graft material, with or without the employment of a shunt, depending upon the condition of the patient, characteristics and location of the aneurysm, and individual experience of the surgeon. In instances wherein suitable graft material is not available, and the aneurysm does not lend itself to tangential resection, wrapping with reactive polyethylene, as described here, would seem to be a safe procedure, offering considerable benefit to the patient. No case of rupture following such a procedure has been reported to our knowledge. In case of progression in size of the aneurysm, or should symptoms warrant, a more extensive attack may be considered at a later date.

SUMMARY AND CONCLUSIONS

The records of all patients admitted to a large Veterans Administration Hospital with the diagnosis of fractured ribs were reviewed. Seventeen patients, 10 per cent, had fracture of a first rib. With the exception of 1 patient, all of these were produced by closed chest trauma, in most instances by sudden deceleration in an automobile accident in which the chest sharply struck the steering wheel.

Complications occurring in the latter series included two grave lesions involving structures within the mediastinum, one an esophageal diverticulum with tracheoesophageal fistula, diagnosed six months after injury, the other a fusiform aneurysm of the aortic arch, diagnosed more than two years after injury. The former lesion was treated by division and repair, the latter by wrapping with reactive polyethylene, both with good postoperative result.

Other complications in cases of first rib fracture included injury to brachial plexus and stellate ganglion, and an unusual obstruction of both subclavian veins from the pressure of excessive callus about healing bilateral fractures. Remaining complications in this group, and all of those in the series of fracture of ribs other than the first (except one instance of brachial plexus injury in a patient with fractures of second rib and clavicle), were the common sequelae of pleural puncture by the rib fragments.

The world literature pertinent to first rib fracture, traumatic tracheoesophageal fistula, and traumatic aneurysm of the thoracic aorta, has been reviewed.

On the basis of this survey, the following conclusions seem to be in order:

1. Trauma, sufficient to produce fracture of a first rib by indirect force, is capable of effecting injury to mediastinal soft parts.

2. Lesions of lesser magnitude than complete disruption of tracheobronchial tree or great vessel may be considerably delayed in development or in producing diagnostic symptoms or signs.

3. In dealing with closed thoracic injuries, especially those produced by high speed automotive accidents, one is obligated to search carefully for evidence of first rib fracture, which may be easily overlooked before callus formation begins.

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2. Lesions of lesser magnitude than complete disruption of tracheobronchial tree or great vessel may be considerably delayed in development or in producing diagnostic symptoms or signs.

3. In dealing with closed thoracic injuries, especially those produced by high speed automotive accidents, one is obligated to search carefully for evidence of first rib fracture, which may be easily overlooked before callus formation begins.

4. Patients suffering such fractures, without early manifestations of mediastinal lesion, must be thoroughly examined at frequent intervals; for at least two years following injury. Each examination should include an x-ray of the chest.

5. Widening of the superior mediastinal shadow in the vicinity of the aortic arch following chest injury should be considered a sign of possible incomplete rupture of the aorta, or other great vessel, from which aneurysm may develop.

ADDENDUM

Since submission of the manuscript, an additional pertinent case has been treated at the Hospital of The University of Mississippi. This case will be reported in detail elsewhere,* but may be briefly described here.

The patient (B. W.), an 18-year-old Negro girl, was transferred from another hospital on Oct. 12, 1955, four weeks following an automobile accident. On admission she was found to have fractures of *both first ribs,* left clavicle, right radius, and right femur. The left lung was completely atelectatic. Bronchoscopy revealed complete occlusion of the left main-stem bronchus, 3 cm. beyond the carina. The patient had no respiratory distress and was afebrile. A diagnosis of complete severance of the left bronchus was made. Operation was deferred because of associated orthopedic conditions.

Left thoracotomy was performed on Dec. 7, 1955. The bronchus was found to be completely divided, and the ends separated. The bronchus was reanastomosed and the lung re-expanded. Two weeks after surgery, the left lung was well expanded and there was a minimum of pleuritic reaction.

Patient H. F. M. (No. 16, Table I) was seen on Mar. 22, 1956, fourteen months after the aortic aneurysm was wrapped with reactive polyethylene. Chest x-ray on that date revealed no change in the aortic shadow compared with films taken six months and eleven months previously. He has remained asymptomatic and able to work.

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COMPARATIVE STUDY OF POSTRESECTION MORBIDITY IN CASES WITH AND WITHOUT PRERESECTION THORACOPLASTY

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EXCISIONAL surgery in the treatment of pulmonary tuberculosis has led to gratifying results.[1-7] However, the method of obliteration of the pleural space following resection is still controversial. Various ways of coping with the situation, such as temporary phrenic paralysis, pneumoperitoneum, postresection thoracoplasty, concomitant thoracoplasty, extrapleural plombage, extrapleural pneumothorax, extraperiosteal plombage, pleurotent, etc., indicate the lack of uniformity in dealing with this problem. There are also some of the opinion that there is no need for any space-reducing procedure following resection unless a definite pleural complication, in the form of a persistent bronchopleural fistula and empyema, is present.[8] The controversy still exists today and each thoracic surgeon employs his own preferred method in handling the situation.

The idea of a space-reducing, preresection thoracoplasty has some appeal. This paper is a report of a comparative study of the postoperative morbidity in 135 consecutive pulmonary resections performed at the Battey State Hospital from August, 1950, to August, 1953. Resections performed because of thoracoplasty failure, pneumonectomies, and lower lobectomies have been excluded. Seventy patients who had not had preresection thoracoplasty and 65 who had resections performed after a thoracoplasty, some three weeks before the resection, were studied.

The type of preresection thoracoplasty done in this series consists of the subperiosteal resection of the second and third ribs, posteriorly, from the level of the transverse process to, anteriorly, within the mid-clavicular line, or anterior axillary line, depending upon the anticipated amount of space reduction necessary following the contemplated surgery. The undersurface of the first rib has also been stripped of the periosteum.

The complications studied in the postoperative period and used for comparison between the two groups are as follows: (a) difficulty in expectoration in the first forty-eight hours, necessitating repeated tracheal aspiration and/or bronchoscopic aspirations, (b) evidence of a small leak from the raw surface, as manifested clinically by delayed re-expansion of the remaining lung tissue as shown by x-ray, blood-tinged sputum, and the necessity for prolonged underwater deflation, (c) poor re-expansion of the lung, necessitating thoracentesis or the reinsertion of an intrapleural catheter, (d) definite bronchopleural fistula

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requiring further thoracoplasty for space obliteration, and (e) a definite purulent empyema necessitating drainage when thoracoplasty failed to correct the causative bronchopleural fistula

Table I specifies the distribution of cases in regard to the extent of resection and shows a more or less comparable proportion in the two groups

TABLE I EXTENT OF RESECTION

	WITH PRERESECTION THORACOPLASTY	WITHOUT PRERESECTION THORACOPLASTY
Lobectomies	23	32
Segmental cases	42	38
Total number of cases	65	70

From Table II it seems that patients who have preresection thoracoplasty have a lower incidence of complication than those without This will be more evident when the rate is divided among various types of complications (one case may *have more than one complication)* *Table II also shows that the main* difference in incidence of complication is in the patients in whom lobectomy was performed This will be elaborated in Table III

TABLE II COMPLICATIONS

	WITH PRERESECTION THORACOPLASTY	WITHOUT PRERESECTION THORACOPLASTY
Lobectomies	8	22
Segmental cases	10	8
Total number of cases	18	30

TABLE III INCIDENCE OF VARIOUS TYPES OF COMPLICATIONS WITH RESPECT TO EXTENT OF RESECTION

	WITH PRERESECTION THORACOPLASTY			WITHOUT PRERESECTION THORACOPLASTY		
	SEGMENTAL	LOBAR	TOTAL	SEGMENTAL	LOBAR	TOTAL
a Difficulty in expectoration	8	7	15	2	6	8
b Evidence of prolonged leak	2	3	5	4	16	20
c Poor re expansion of lung	3	2	5	5	14	19
d Bronchopleural fistula	2	1	3	0	5	5
e Empyema	0	1	1	0	1	1

After studying Table III, the following points are made evident (1) There was a higher percentage of patients who had difficulty in expectoration in the group that had preresection thoracoplasty (2) The major causes of post operative morbidity, as evidenced by prolonged leak of air and poor re expansion of the lung necessitating only minor corrective *procedure is about 1 to 4 in* favor of those with preresection thoracoplasty (3) Cases with previously performed space reducing *thoracoplasty are less likely* to result in bronchopleural fistula (4) The incidence of residual empyema, resulting from bronchopleural fistula, not amenable to postresection thoracoplasty, is about equal in those with and without preresection thoracoplasty This seems to indicate that the collapse obtained is not as satisfactory in patients who have had a preresection thoracoplasty as in the patients who have not and whose chest wall, lacking the rem ribs, is more pliable. (5) Finally, it seems that the difference in the incidence of complication is most marked in cases where lobectomy was performed (20 against 5 and 19 against 5), in the "b" and "c" categories, respectively. This, we believe, indicates that the ease of obliteration of pleural space is more significant in reducing such complications than the presence of the so-called raw surfaces at the segmental plane, as in segmental resections.

DISCUSSION

It is at once apparent that a preresection thoracoplasty calls for an additional stage of operation and with it the inherent danger of anesthetic accident, cardiac arrest, prolonged hospitalization and expense, increased suffering, psychic trauma, transfusion reaction, etc. It might also be said that a thoracoplasty disturbs the ventilatory function on the side of the operation, if not also on the contralateral side, as well as diminishes the remaining respiratory function on the side on which the operation has been performed.[8-10] However, on the assumption that the diaphragm is responsible for 70 per cent of the function of one lung and the intercostal musculature for the remaining 30 per cent, it appears that the disturbance of a two-rib resection is not likely to be a great detriment to the respiratory function on that side. We feel that, although we have no objective findings as to the amount of reduction of the respiratory function on the side of the operation by the type of preresection thoracoplasty we do, it should not be any more deleterious than allowing the diaphragm to overelevate, thus attenuating its function, and overdistending the rest of the lung, as happens in cases where no preresection thoracoplasty is done. This is especially believed to occur, should any pleural complications arise, as there is a greater likelihood of delayed obliteration of the pleural space in the latter group.

In cases where a postresection thoracoplasty is indicated, the disadvantage of additional operation and chest-wall deformity in the group with preresection thoracoplasty therefore does not exist. Even in cases which do not require postresection thoracoplasty, we believe, from the experiences presented in this paper, that the undesirable feature of an additional operation is, in most cases, balanced by the advantages in the postresection period. We also feel that this operation, in poor and questionable risk cases, provides an acute test as to the ability of the patient to undergo chest surgery.

A point worthy of mention is the "reversibility" of such preresection thoracoplasty. It has been found that one is able to convert the relaxing and space-reducing type of thoracoplasty into a definitive Alexander type in the second stage, if, for various reasons, a resection is found to be contraindicated, during or after the preresection thoracoplasty. This revision and second-stage thoracoplasty, consisting of removal of the first rib and the transverse processes of the second and third thoracic vertebrae and the removal of additional ribs and processes as indicated, is found to be well tolerated, with no dangerous amount of paradoxical motion of the decostalized chest wall.

As to the one-stage combined thoracoplasty and resection which was propounded by Iverson,[11] Samson,[12] and Conklin,[13] there seems to be unanimous agreement that it is desirable in selected cases only. It is also the consensus that, in spite of the various advantages of this one-stage procedure, the postoperative morbidity is definitely increased Stead,[14] in his excellent articles, has conclusive evidence to that effect Its usefulness, therefore, is limited Bjork[15] favors a combination of pulmonary resection and his osteoplastic thoracoplasty, which is said to obviate the dreaded paradoxical motion of the decostalized chest wall We have had no experience with that particular technique

Last, but not of least significance, we feel that the preresection thoracoplasty affords the diseased area of the lung an opportunity to undergo a period of "selective collapse," a desirable condition which most of the phthisiologists in the days of artificial pneumothorax strove to obtain This period of time between the preresection thoracoplasty and actual resection also allows adjustment of aerodynamics of the remaining and comparatively healthy lung We believe such features should render the resection a safer procedure

CONCLUSION

From the study of two more or less comparable groups of patients who have had pulmonary resection for tuberculosis, those with and those without preresection thoracoplasty, the data tend to show that the postoperative morbidity is four times less in patients who have had a preresection relaxing operation The various merits and disadvantages of this procedure are discussed We believe that, in selected cases, when a resection of lobar extent and a space reducing problem are anticipated, a relaxing thoracoplasty done prior to pulmonary resection is of considerable value in reducing the postoperative morbidity

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GIANT AIR CYST(S) AS A SEQUELA OF PULMONARY TUBERCULOSIS

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OUR attention has been directed recently to a series of patients, in this 1,800 bed hospital for pulmonary tuberculosis, who have in common a giant air-containing cystic space in the lung. These patients all had diagnoses of pulmonary tuberculosis and had been under treatment for different lengths of time. The air cysts in the lung fields found on x-ray could all be traced from areas of tuberculous infiltration in the series of films taken over the period of time while the patient was in the hospital. They represented the end result of continuous resolution and regression of the tuberculous process. They met all the criteria, roentgenologically, to be diagnosed as giant bulla of the lung, or pneumatocele. Resections were performed on all these patients and the specimens were examined pathologically. To our added amazement, no histopathologic evidence of tuberculosis could be found in the sections. Therefore, it seems that, were it not for the fact that these cases represent the sequelae of treated pulmonary tuberculosis, one would have no way of differentiating these cases from those of pneumatocele of other etiology. We believe that it might be worth while to present our experience and findings in these cases.

CASE REPORTS

CASE 1.—L. S. F. (B.S.H.), an 18-year-old Negro girl, was admitted to this institution on Nov. 24, 1952, with a diagnosis of pulmonary tuberculosis, far advanced. In addition, tuberculous complications of lymphadenitis, adenitis, and bronchitis were present. X-ray at the time of admission showed extensive involvement of the left lung, with almost total destruction, together with scattered disease in the right lung field (Fig. 1). On admission the patient was placed on streptomycin and para-aminosalicylic acid, which she received for approximately one year. In October, 1953, the patient was started on isoniazid and para-aminosalicylic acid, which she received up until the time of surgery. The sputum converted in October, 1953, and has remained negative since that time. The patient did remarkably well on the medical regime. The lesion in the right lung resolved nicely, but the patient progressed to the formation of giant bullas and emphysema in the left lung. A bronchogram made in the preoperative period showed damage to the entire left bronchial tree. In view of the destroyed lung, with large pneumatoceles present (Fig. 2) the patient was accepted for surgical therapy. On Feb. 10, 1955, a left pneumonectomy and concomitant thoracoplasty were done. The postoperative course was entirely uneventful and the patient was transferred back to the Medical Service in good condition, with no symptoms, sputum negative, and no respiratory embarrassment. The pathologic examination of the resected material showed complete destruction of the left lung, with giant, openly drained, air-containing spaces present in the resected lung. Direct smears and cultures of all upper lobe bronchi and corresponding parenchymatous lesions were negative for acid-fast bacilli. The patient is now (Oct. 1, 1955) being prepared for discharge.

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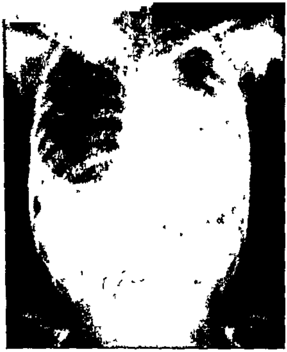

Fig. 1.

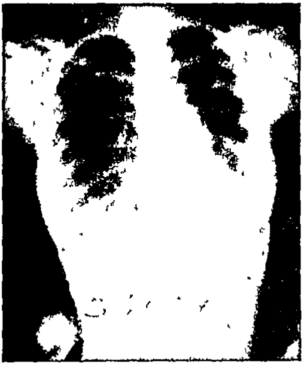

Fig. 2

CASE 2.—C. J. (B.S.H.), a 23-year-old Negro man, was admitted March 26, 1951, with a diagnosis of pulmonary tuberculosis, far advanced. On admission the patient was started on pneumoperitoneum, which was maintained up until the time of surgery. Streptomycin and para-aminosalicylic acid were given for a total of eleven months after admission and then isoniazid and para aminosalicylic acid were instituted in March, 1952. In addition to this, streptomycin was again instituted in July, 1952. The sputum converted in March, 1952, and remained negative until the time of surgery. At the time of admission, roentgenographically, the patient showed an essentially clear right lung, with exudative involvement throughout the left lung (Fig. 3). Under treatment, the lesions in the left lung underwent considerable resolution, leaving behind numerous thin-walled, cystic lesions throughout practically the entire left lung (Fig. 4). A bronchogram made in October, 1952, showed extensive bronchiectasis of the left upper lobe, as well as the left lower lobe. In view of the extensive destruction, the patient was seen in surgical consultation and accepted for excisional surgery. On Jan. 15, 1954, a preresection thoracoplasty was done, with the removal of the second and third ribs and lysis of the first rib. On Feb. 3, 1954, the patient had a left upper lobectomy and removal of the superior segment of the left

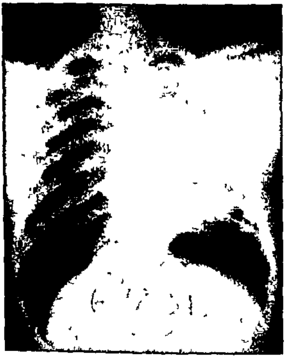

Fig 3.

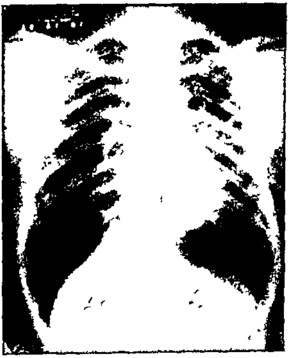

Fig. 4.

lower lobe. The decision to save the basal segments of the lower lobe was made at the time of surgery, when it was felt they were essentially free of palpable disease and would represent a significant amount of functioning lung. The postoperative course, however, was marred by persistent localized pneumothorax at the apex of the pleural cavity and on Feb. 24, 1954, a postresection tailoring thoracoplasty was done, with complete obliteration of the residual air space. The postoperative course, henceforth, was entirely uneventful. The pathologic examination of the resected specimen showed a large, empty, upper lobe pneumatocele and saccular bronchiectasis, most marked in the lingula bronchus. All cultures of resected material were negative for acid-fast bacilli. The patient, being asymptomatic, was discharged Aug. 18, 1954, with a negative sputum. He was to continue drug therapy at home and was on a limited exercise status.

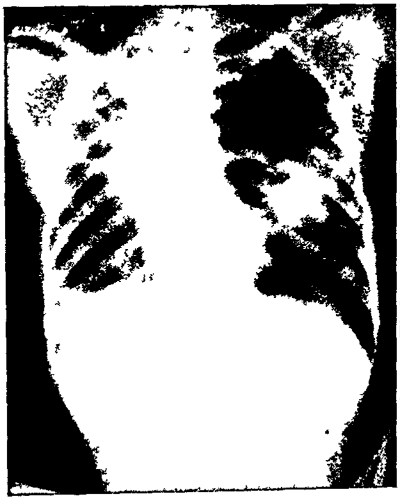

Fig. 5.

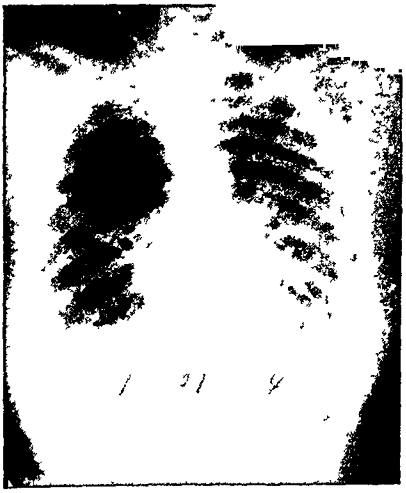

Fig. 6.

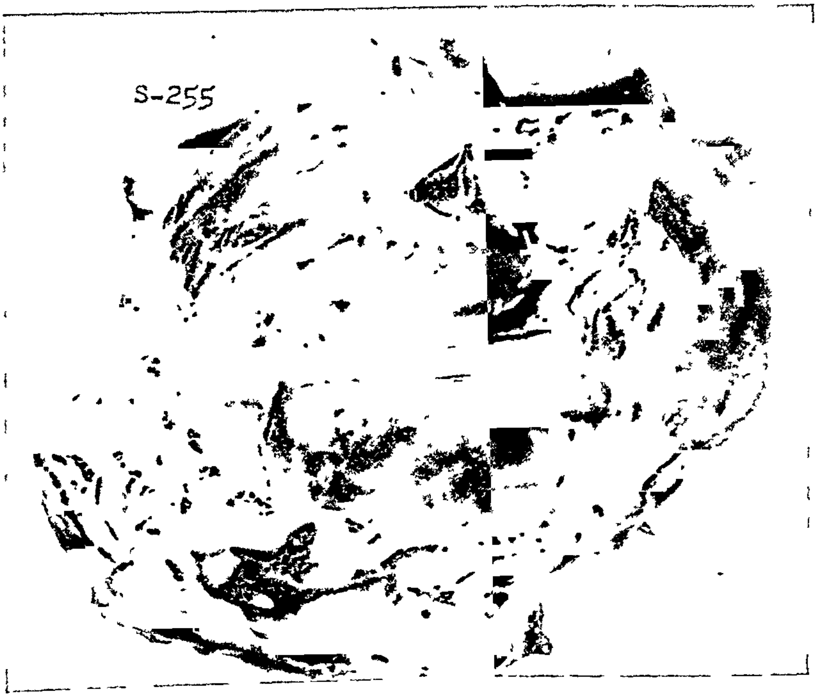

Fig. 7.

CASE 3.—A. A. (B.S.H.), a 28-year-old Negro woman, was admitted Feb. 9, 1953, with a diagnosis of pulmonary tuberculosis, far advanced; sputum positive. On admission the patient was given streptomycin, isoniazid, and para-aminosalicylic acid for forty weeks and then started with isoniazid and para-aminosalicylic acid which she received up until the time of surgery. The last positive sputum was a culture in March, 1953. Since that time the sputum has remained negative. Roentgenographically, at the time of admission, the patient showed extensive pneumonic and cavitary involvement of the right upper lung, with scattered disease in the lower portion of the right lung, as well as mid-lung field spread with cavitation of the left lung (Fig. 5). The disease responded very nicely to the drug therapy, with complete resolution of the disease in the left mid-lung field. The right lung underwent a considerable amount of resolution, but with the development of a giant air-containing cyst in the upper right lung field (Fig. 6). In view of this finding, the patient was accepted for excisional surgery. On Nov. 4, 1954, a right upper lobectomy was done. At the time of surgery, the giant air-containing cyst was seen to occupy the entire right upper lobe, with the right middle and right lower lobes presenting a satisfactory appearance. The postoperative course was essentially smooth. The pathology of the resected material revealed one large air-containing, cystlike structure, with moderate bronchiectasis and some atelectasis (Fig. 7). Cultures of the resected material failed to show a growth for acid fast bacilli. The patient was discharged home. The sputum remains negative by smear and culture.

CASE 4.—M. R. (B S.H.), a 22-year old Negro woman, was readmitted to this institution on Dec. 8, 1952, with far-advanced pulmonary tuberculosis, bilateral (Fig. 8). The previous admission had been in December, 1949, and during that time she was hospitalized approximately twenty eight months, received pneumoperitoneum and a short course of streptomycin and para aminosalicylic acid. The sputum was positive at the time of discharge. On the present admission the sputum was positive on direct smear. In the last admission the patient was treated with streptomycin, isoniazid, and para-aminosalicylic acid. She received approximately twelve months of this therapy and in January, 1954, she w
para aminosalicylic acid, which she received up until the time o
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quite well to the medical regimen, the disease in the

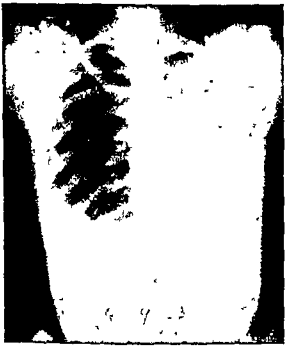

Fig 8

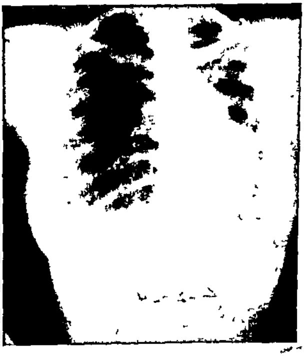

Fig 9.

tion and contraction and assuming a stabilized appearance. On the left side the disease progressed to destruction, with multiple giant cystic areas (Fig. 9). In view of the giant air-containing cysts remaining in the left lung, the patient was accepted for surgical therapy. On June 10, 1954, a left pneumonectomy with concomitant thoracoplasty was done. The postoperative course was quite smooth, with no evidence of respiratory embarrassment in the postoperative period. The patient was discharged April 29, 1955, with two-hour exercise and was entirely asymptomatic. The sputum remained negative.

Case 5.—B. B. J. (B.S.H.), a 17-year-old white girl, was admitted April 8, 1953, with a diagnosis of pulmonary tuberculosis, far advanced; sputum positive. Since admission the patient has received streptomycin and para-aminosalicylic acid, as well as isoniazid for approximately one year. The sputum converted in April, 1953, and remained negative up to the time of surgery. Roentgenographically, at the time of admission, she showed an essentially clear left lung. The right lung was occupied by exudative pneumonic involvement of the entire lung (Fig. 10). The disease responded nicely to drug therapy, with resolution of the exudative components. She was left with a residual, however, of numerous air-containing cystlike structures and the general appearance of the left lung was that of a completely destroyed left lung (Fig. 11). A bronchogram made May 5, 1954, showed total destruction of the left lung. In view of the destroyed lung, with bronchiectasis, the patient was accepted for surgical excision. On Aug. 11, 1954, the patient had a left pneumonectomy and a concomitant thoracoplasty. The postoperative course was entirely uneventful. Pathologic examination of the resected left lung showed a large-grained upper lobe cyst with tubular and saccular bronchiectasis. There were also small cavities in the posterobasal segments of the left lower lobe. Smears of the resected material were positive. However, cultures of this material were all negative. This patient is continuing to do quite well. She has been discharged to her home with sputum negative on smear and culture and is entirely asymptomatic with no respiratory embarrassment.

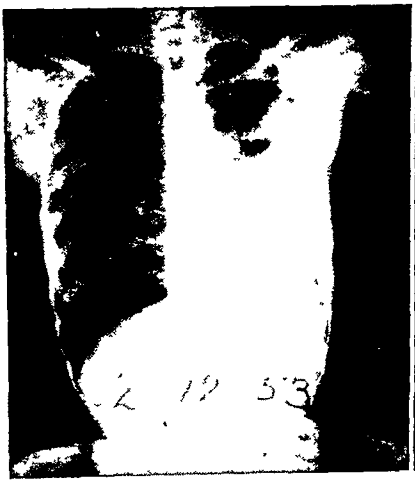

Fig. 10.

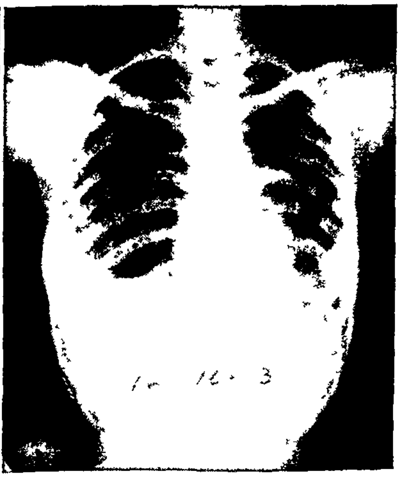

Fig. 11.

Case 6.—D. M. (B.S.H.), a 26-year-old Negro man, was admitted to this hospital April 12, 1954, with a diagnosis of pulmonary tuberculosis, far advanced, and tuberculous complication of right pleuritis. On admission the sputum was positive on direct smear. The chest x-ray on admission revealed, on the right side, a huge cavity in the upper half and soft, scattered shadows of infiltration throughout the remaining portion of the right lung and the whole of the left lung (Fig. 12). Soon after admission the patient was given drug therapy, which consisted of streptomycin and para-aminosalicylic acid, with amazing clinical improvement. The sputum converted to negative two months after admission and has remained negative. One year after admission, roentgenograms showed a destroyed upper lobe on the right side, which was replaced by a giant pneumatocele, occupying almost two-thirds of the right pleural space (Fig. 13). A bronchogram revealed the middle and lower lobes to be compressed toward the base of the pleural cavity and the superior division of the lower lobe on the right side to be bronchiectatic. On May 24, 1955, a right upper lobectomy and resection of the superior segment of the lower lobe were done, and a small wedge from the basilar division of the right lower lobe was removed, along with a tailoring thoracoplasty. The postoperative course was essentially benign, except for the necessity of frequent tracheal aspirations, as the patient was not able to expectorate secretions effectively. As of Sept. 1, 1955, this patient has been doing very well. He is now three and one-half months postoperative and, by x ray, the remaining lung has completely re-expanded. The sputum remains negative. The resected specimen revealed one large "healed" cavity of the right upper lobe and several "healed" cavities of the superior division of the right lower lobe, with one active focus of residual fibrocaseous tuberculous disease and one minute focus of residual tuberculous endobronchitis of the superior division. Direct smears and cultures of the resected specimens were negative for acid-fast bacilli.

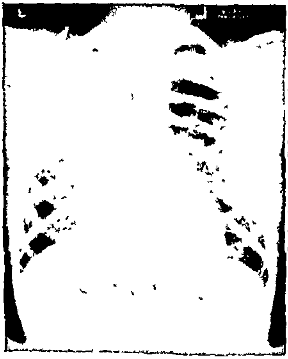

Fig 12.

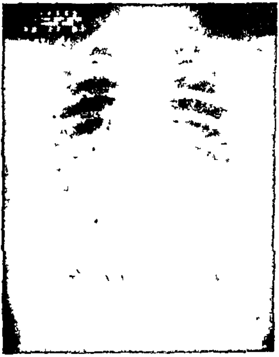

Fig. 13.

COMMENT

The subject of etiology and classification of various types of air spaces in the lung has long been well discussed and the medical literature already shows an overabundance of such articles. It is not the purpose of this paper to confound this crowded matter of discussion further. Since 1952, Cooke and Blades[1] have greatly clarified many aspects of this disease entity. It is now agreed that such an acquired form of air cysts of the lung develops as a result of the contraction of the surrounding tissue and the breakdown of the interalveolar septa and the coalescence and distention of the bulla. This mode of formation seems to be quite applicable to the air cysts in this particular series. This paper is an attempt to call attention to the fact that such pathology of the lung does occur as a sequela of "healed" cases of pulmonary

From summaries of the 6 cases presented, it is to be noted that no histopathologic evidence of tuberculosis could be recognized in the excised specimens. Since 3 of the 6 patients had pneumonectomies, this lack of any residual tuberculosis deserves special consideration. Although it is understood that the modern antituberculosis measures and drugs can and do resolve a tuberculosis process in the lung, the completeness of the resolution is perhaps not quite appreciated. We are quite aware of the fact, however, that this is the exception rather than the rule.

Numerous cases which have not been included in this series, and which present more or less similar x-rays, are found after resection to be residual tuberculous cavity with active granulation tissue. They are not included in this series as their appearance does not exactly resemble that of the average giant cyst or cystic disease of the lung. Nevertheless, they are all thin-walled areas of increased radiotranslucency with no peripheral infiltration. As yet, we have not been able to discern any roentgenologic points of differentiation between the two groups.

Another point of interest lies in the question of desirability, if not of necessity, of antituberculosis drug therapy in these patients in the postoperative period, particularly in those patients who have had pneumonectomies and who show no evidence of tuberculosis in the entire lung. The question of necessary hospitalization also deserves to be seriously considered. Believing that tuberculosis is a systemic disease, it is our practice to treat such patients as any other tuberculosis patient who has had a resection. We do not believe, however, that this question is settled.

Our comment would not be complete if the question of the existence of "healed" tuberculous cavity is not brought out. The finding of a giant air cyst connecting directly to a lobar bronchus at the site of a previous cavity cannot be disregarded. Is it not possible that the contraction of surrounding tissue and distention of the original tuberculous cavity, which has been "sterilized" and "endothelized" by the antituberculosis drug, could happen hand in hand with the formation of some of these air cysts of the lung in a previously tuberculous patient?

SUMMARY

Six cases of giant air cysts of the lung in patients with previously proved pulmonary tuberculosis have been presented. The question of the pathogenesis of such lesions in which microscopic study shows no histopathologic evidence of tuberculosis has been raised.

REFERENCE

1. Cook, N., and Blades, B.: Cystic Disease of the Lungs, J. THORACIC SURG. 23: 546-569, 1952.

LEFT CERVICAL, RIGHT THORACIC APPROACH FOR RESECTING CARCINOMA OF THE UPPER ESOPHAGUS

IRVING M ARIEL, M D ,
NEW YORK, N Y

NUMEROUS methods have been devised for resecting the upper third of the esophagus since this was first successfully performed by Garlock in 1937 The various modifications have been efforts to obtain either better exposure to facilitate the resection of the cancer-bearing esophagus, or to effect a reconstruction of the continuity of the food-bearing tube Among the latter have been the utilization of intra abdominal organs (stomach jejunum, colon) transposed to the thoracic region and anastomosed either high in the thorax or in the neck Each of the described procedures has certain advantages and limitations The utilization of a left cervical incision, which takes advantage of the normal deviation of the esophagus to the left side of the neck, combined with a right thoracic incision, which avoids the difficulties inherent in dissecting about the arch of the aorta, has afforded the ready resection of a large segment of the esophagus The techniques of this approach and the method of reconstruction shall be described in detail

The patient was a 57 year old white woman who presented a history of dysphagia of seven months' duration One year previously she had consulted a local medical doctor who diagnosed a gastric ulcer and treated her with diet Seven months before, she had developed dysphagia which had been progressive An esophagram revealed an extensive obstruction which extended from the level of the pharynx inferiorly for a distance of over 8 cm There had been a loss of 20 pounds during the preceding year, erratic bouts of fever of unknown etiology, and repeated "sore throats "

The past history of this patient was significant in that she had had a carcinoma of the thyroid removed thirty eight years previously and had been given large doses of x ray postoperatively

Physical examination was not remarkable, and the patient was found to be in a rather good state of nutrition despite dysphagia of almost a year's duration The neck presented evidence of radiation fibrosis, the result of previous x ray therapy The remainder of the physical examination was negative

Laboratory studies were normal Blood count was within normal range hemoglobin 84 per cent, red blood count 4 3 million per cubic millimeter, white blood count 6,300 per cubic millimeter Tests of liver function revealed phorus 3 6 mg per cent, alkaline phosphatase 3 1 S J R units bilir

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mg. per cent, cephalin flocculation 1+, thymol turbidity less than 5 units, total protein 6.5 Gm. per cent, albumin 3.2 Gm. per cent, globulin 3.1 Gm. per cent, choline esterase 0.55 units.

An esophagoscopy revealed almost complete esophageal obstruction and a biopsy was positive for papillary carcinoma. Accordingly, on June 11, 1954, the resection of the esophagus and repair of the ensuing defect was accomplished in the following manner.

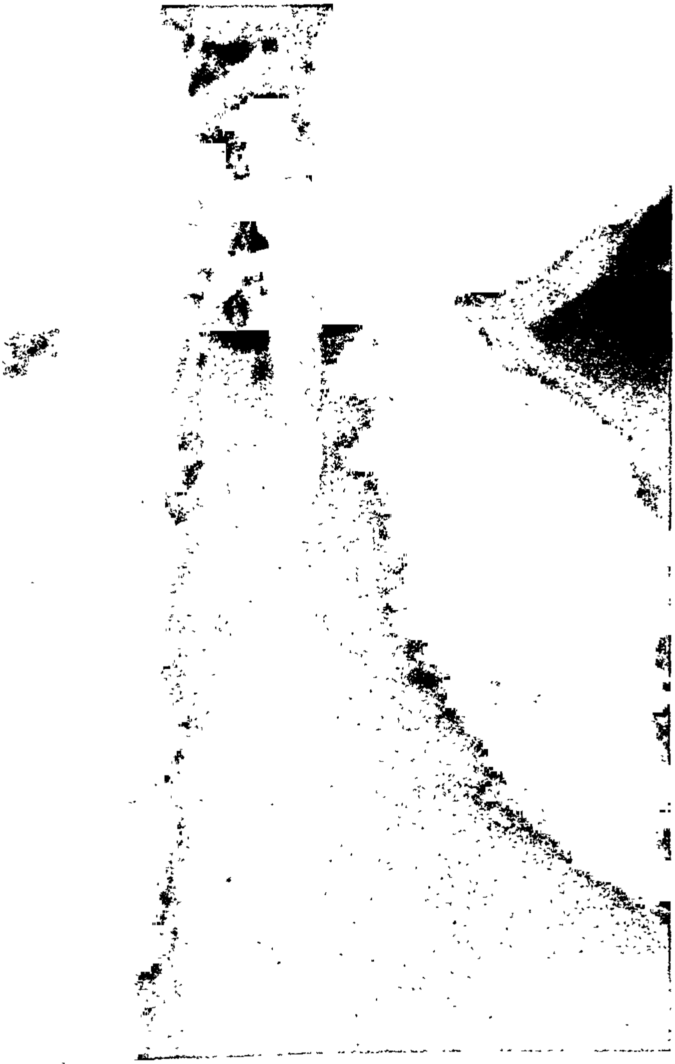

Fig. 1.—An esophagram which reveals a linear obstruction of the cervical and upper thoracic esophagus due to a carcinoma.

OPERATIVE TECHNIQUE*

A left cervical incision was made along the medial border of the left sternocleidomastoid muscle extending from the angle of the mandible to the sternal

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*The operation was performed in conjunction with Dr. James Baldwin.

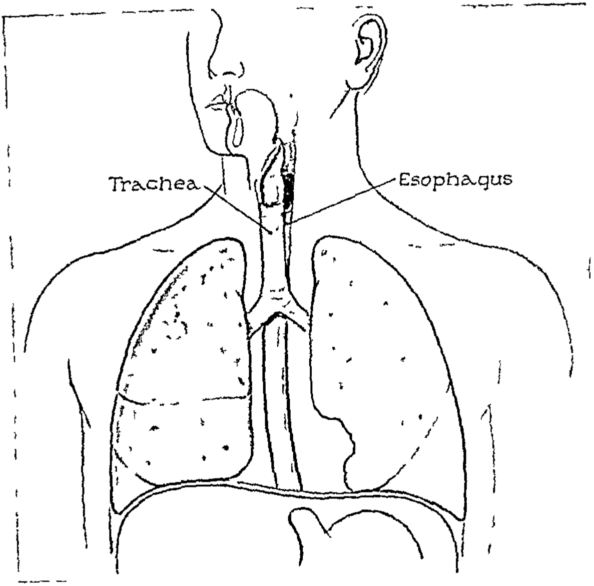

Fig 2—A diagrammatic anatomic drawing illustrating the left cervical deviation of the esophagus A left cervical incision permits excellent exposure for operative manipulation of the esophagus

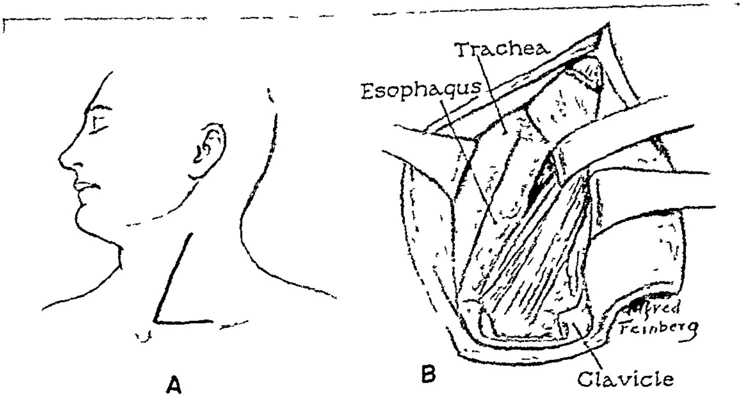

Fig 3—The cervical exposure of the esophagus A, Illustrates the incision used B, The esophagus is exposed The sternomastoid muscle has been removed. muscles are retracted The medial half of the clavicle has been resected due to u vious irradiation (This step is not usually indicated.) The esophagus is visualized

notch, at which point a horizontal component of the incision was made extending laterally toward the left. The skin and subcutaneous tissue which was markedly atrophic and fibrotic, the result of previous irradiation, was retracted and the sternomastoid muscle resected. The clavicle, which was found to be softened and friable (the result of previous irradiation), was mobilized and the medial third resected. The sternohyoid and omohyoid muscles were then severed, and the remaining strap muscles of the neck retracted laterally. This gave excellent exposure of the entire cervical esophagus which was easily mobilized (Fig. 3). The tumor, which was in the lumen of the esophagus, could be felt infiltrating the musculature, but it was definitely limited to the esophagus and had not infiltrated the contiguous structures. The proximal portion of the esophagus at the level of the esophageal-pharyngeal junction was severed, a square of gutta percha was then tied about the distal stump of the esophagus by a long heavy silk thread which was then placed through the sternal region into the right intrathoracic cavity. The distal esophageal stump containing the gutta percha protective covering was then bent on itself and delivered into the mediastinum. The proximal pharyngeal stump was left open (Fig. 4). The wound was then packed with moist saline sponges and temporarily closed with Michel skin clips. It was covered with a moist towel and the patient was then turned to the left side and placed in a position for a right thoracotomy.

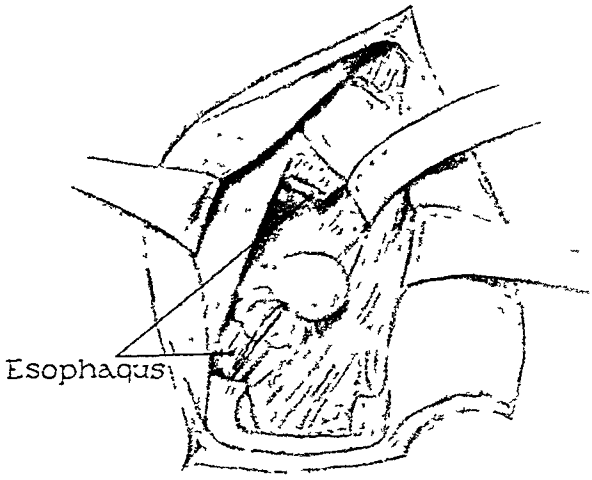

Fig. 4.—The esophagus has been transected at the pharyngo-esophageal junction. A square of gutta percha has been tied about the distal stump of the severed esophagus and the silk string delivered into the right chest.

Thoracic Portion of the Resection.—An anterolateral incision was made in the right chest wall, in an inframammary position. The fifth rib was exposed and removed. This permitted exposure of the right chest cavity. There were a few adhesions of the lung to the surrounding chest cavity, which were freed. The azygos vein was divided, and the esophagus was readily mobilized (Fig. 5).

By gentle traction of the silk thread which had been delivered into the mediastinum during the cervical portion of this operation, the distal severed portion of the esophagus was delivered into the right thoracic cavity (Fig. 6). After the esophagus was completely mobilized, it was transected at a level about 10 cm. distal to the pharyngeal-esophageal junction.

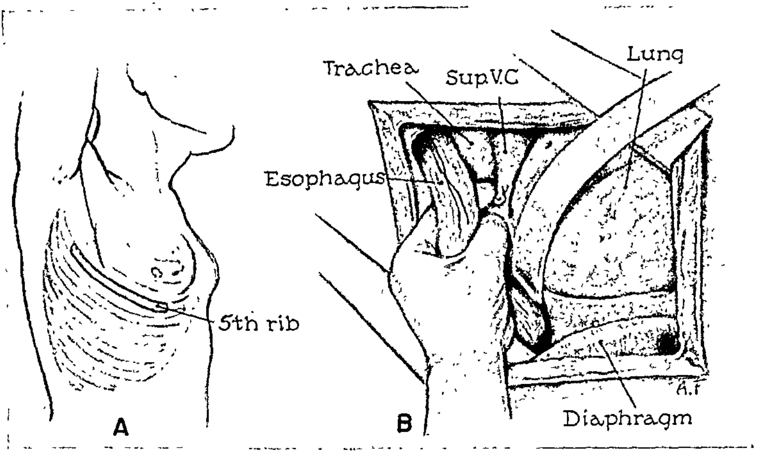

FIG. 5.—The thoracic phase of the esophagectomy. *A*, The anterolateral thoracic incision extending in the inframammary fold. The fifth rib was excised. *B*, The esophagus is mobilized and the string inserted from the cervical region is visualized.

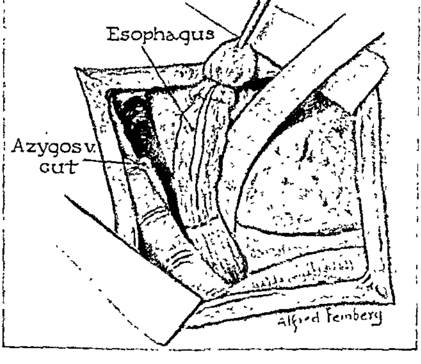

Fig. 6.—Traction on the silk suture delivered the transected esophagus into the chest cavity.

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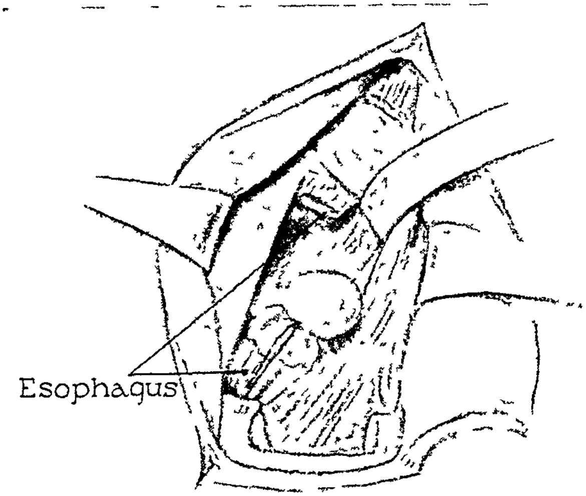

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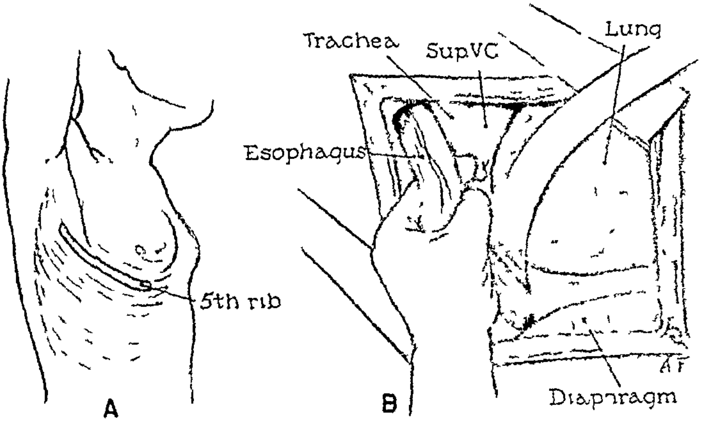

Fig 5 —The thoracic phase of the esophagectomy A The anterolateral thoracic incision extending in the inframammary fold The fifth rib was excised B, The esophagus is mobilized and the string inserted from the cervical region is visualized

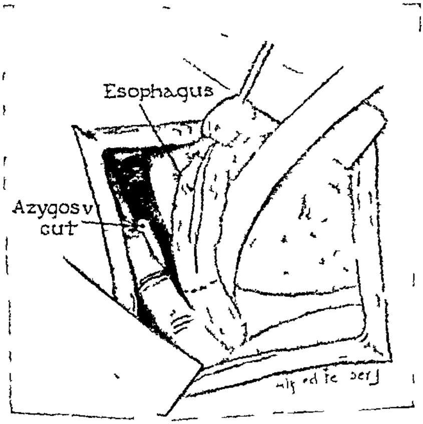

Fig 6 —Traction on the silk suture delivered the transected esophagus into the chest cavity

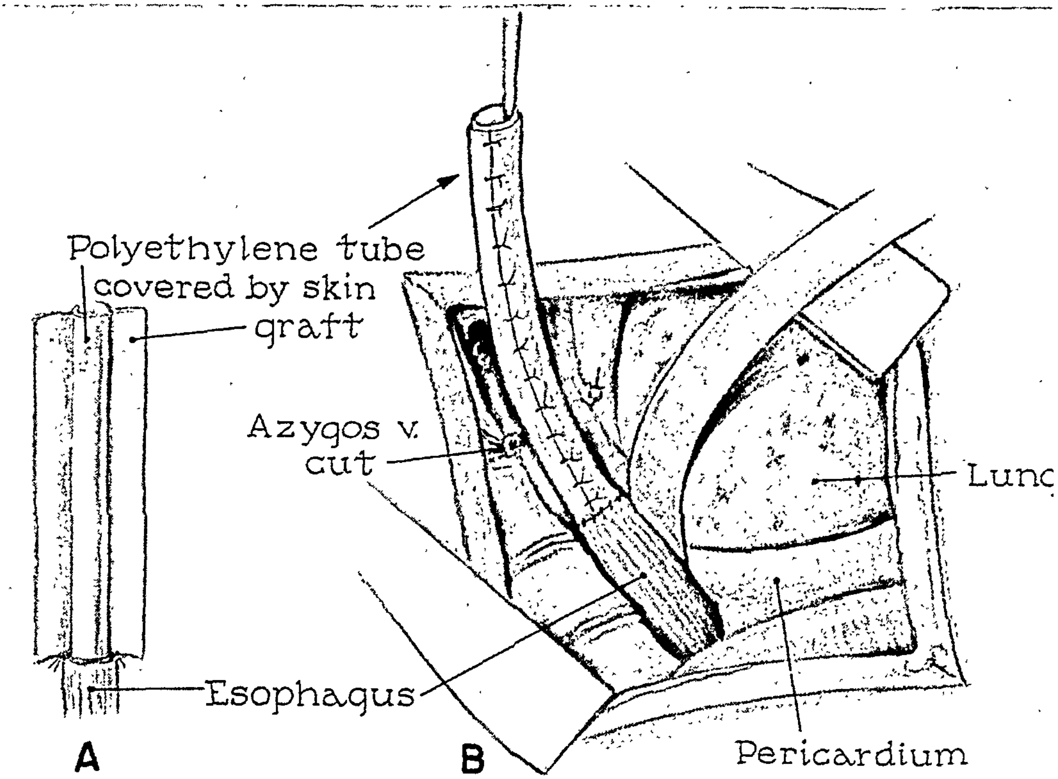

Fig. 7.—The reconstruction of the cervical thoracic esophagectomy. *A*, A split-thick ness skin graft has been molded about a Berman-type polyethylene tube and the skin gra is being anastomosed to the distal esophagus. *B*, The thoracic anastomosis has been complete and the reconstructed esophagus is being delivered into the natural esophageal bed in tl cervical region.

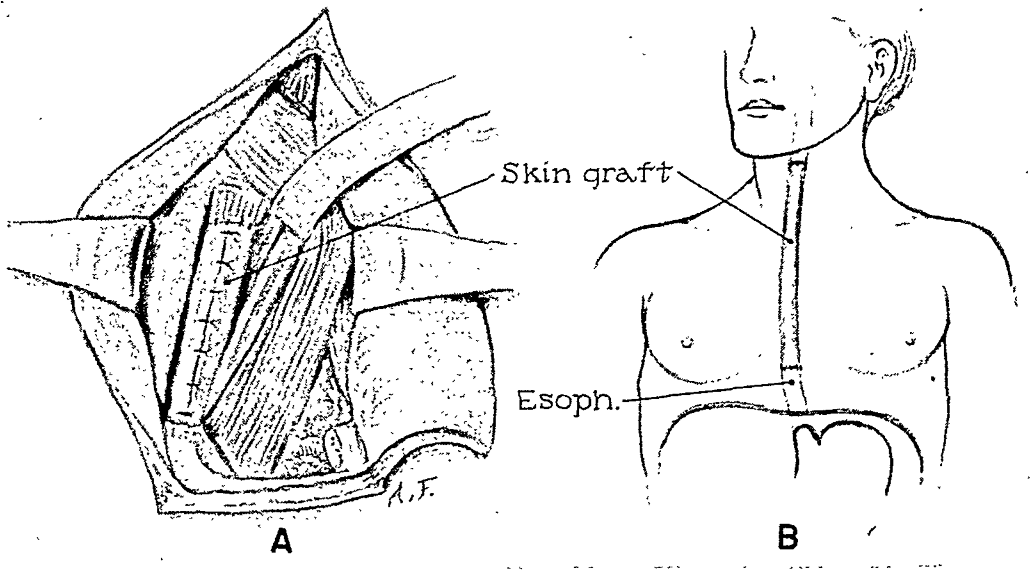

Fig. 8.—*A*, The cervical repair of the reconstructed esophagus. The skin graf has been sutured to the pharyngeal stump. *B*, A diagrammatic representation of a recon structed esophagus.

Repair of the Ensuing Defect.—The resulting defect was closed by utilizing a Berman-type polyethylene tube, about which was placed a split-thickness skin graft taken from the patient's lower abdomen. A flat piece of skin was molded about the polyethylene tube, and the polyethylene tube was then inserted into the distal esophagus, but in no way anchored there. The split-thickness skin graft was sutured by interrupted silk sutures to the distal stump of the esophagus (Fig. 7, *A*). Following this anastomosis, the skin-covered polyethylene tube was placed into the natural bed of the esophagus and delivered into the cervical region (Fig. 7, *B*). The chest wound was then closed in the normal manner, the patient was placed in the supine position and the cervical wound was then reopened. The polyethylene tube was then anchored to the pharynx by two interrupted silk sutures, after which the pharyngeal skin graft anastomosis was made, again utilizing interrupted No. 4-0 silk sutures. The neck wound was closed. A drain was left in the neck wound, and under-water drainage was established for the right thoracic cavity (Fig. 8).

The patient tolerated the procedure well, there was a minimum of blood loss, and a 500 c.c. transfusion was given during this operation which lasted approximately two hours.

POSTOPERATIVE COURSE

Postoperatively there was evidence of leakage from both anastomotic sites. There developed a pharyngeal-cervical fistula with free drainage of mucus and, on efforts to swallow, fluids presented in the left neck region. In addition, there was copious drainage of serosanguineous material from the right chest. This persisted for approximately two weeks, during which time the patient was maintained exclusively on intravenous feedings. Electrolyte abnormalities developed and were corrected. A gastrostomy was performed three weeks postoperatively for feeding purposes, which functioned satisfactorily, and the patient was discharged from the hospital on July 18, 1954.

She then developed an empyema necessitatis due to drainage material which formed a pathway from the left cervical region, through the posterior mediastinum, and thence out through the right chest. The patient was readmitted to the hospital Aug. 5, 1954, and drainage was instituted which cured this complication. She then developed dysphagia and a dilatation of the cervical esophagus was performed on Dec. 21, 1954. She has remained free of evidence of cancer. She now suffers dysphagia on efforts to swallow solid food and a recent esophagoscopy has revealed some stenosis at the anastomotic level. The left vocal cord is paralyzed due to severance of the left recurrent laryngeal nerve.

The resected specimen consisted of a large, polypoid ulcerated tumor which measured over 5 cm. in its largest diameter and encircled approximately five-sixths of the wall of the esophagus. The tumor invaded submucosa and muscularis. Histologically, the tumor was an epidermoid carcinoma, deeply invading the muscularis.

The tissue removed from the posterior mediastinum was examined for presence of metastases from this carcinoma and, although over 15 lymph nodes were removed in this dissection, none was found to contain metastases.

DISCUSSION

This successful resection of a rather extensive cancer of the esophagus demonstrates the feasibility of taking advantage of the normal anatomy of the esophagus to obtain excellent exposure through a double incision. The one in the left cervical region takes advantage of the tendency of the normal esophagus to swing toward the left in the neck and affords excellent exposure for mobilization and dissection of the esophagus in this region. The technique of tying gutta percha around the distal stump of the esophagus and inverting the esophagus into the right chest is similar to the procedure utilized in the abdominoperineal resection of rectal cancer, where the abdominal phase of the operation is concluded by turning the resected bowel on itself and delivering it into the pelvis for removal by means of the perineal approach. The technique has been found to be simple, and in the case herein reported the

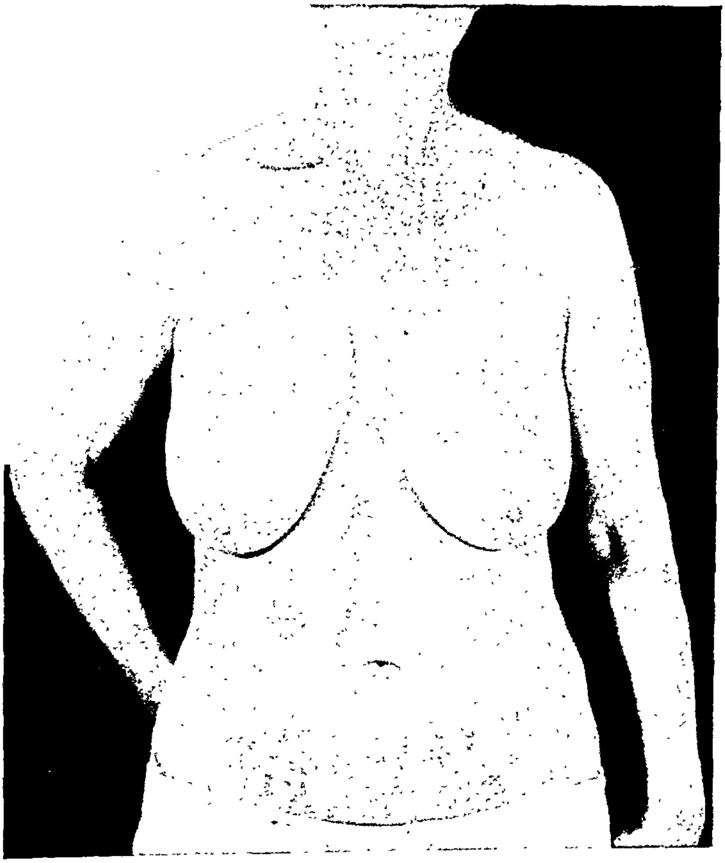

Fig. 9.—The patient one year after operation showing good nutritional status. The scar in the clavicular, upper mediastinal region is the site of previous irradiation, the scar of the lower abdomen is the site where the skin was removed for reconstruction of the esophagus.

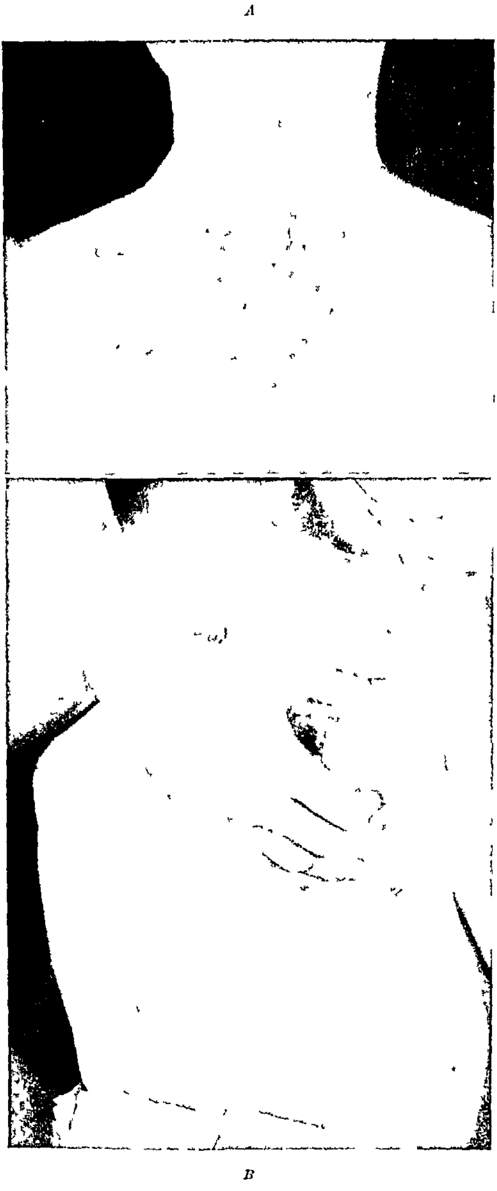

Fig 10—*A*, The left clavical scar one year after operation *B*, The right thoracic incision one year after operation

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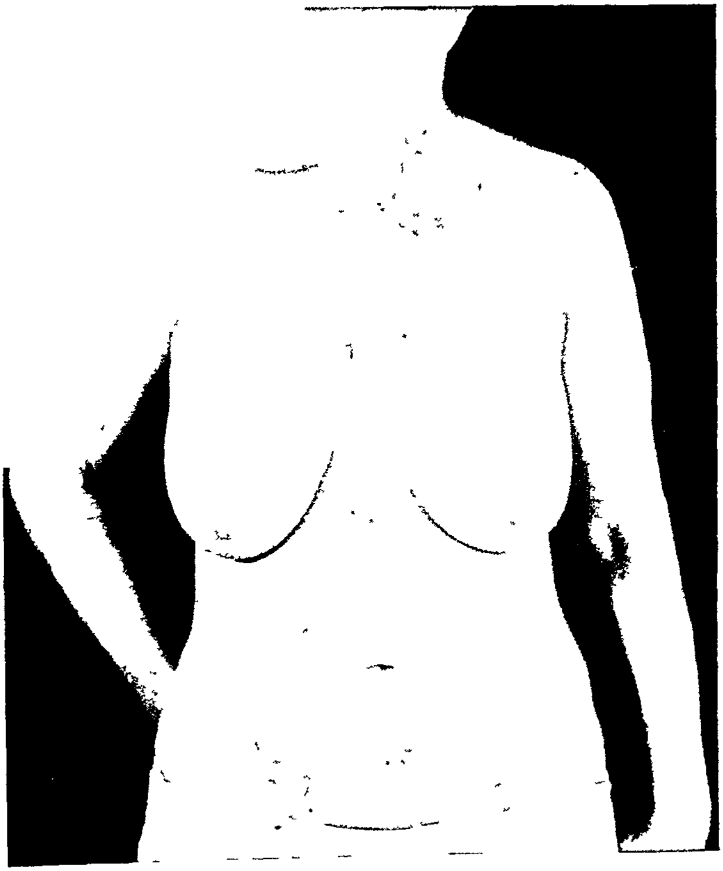

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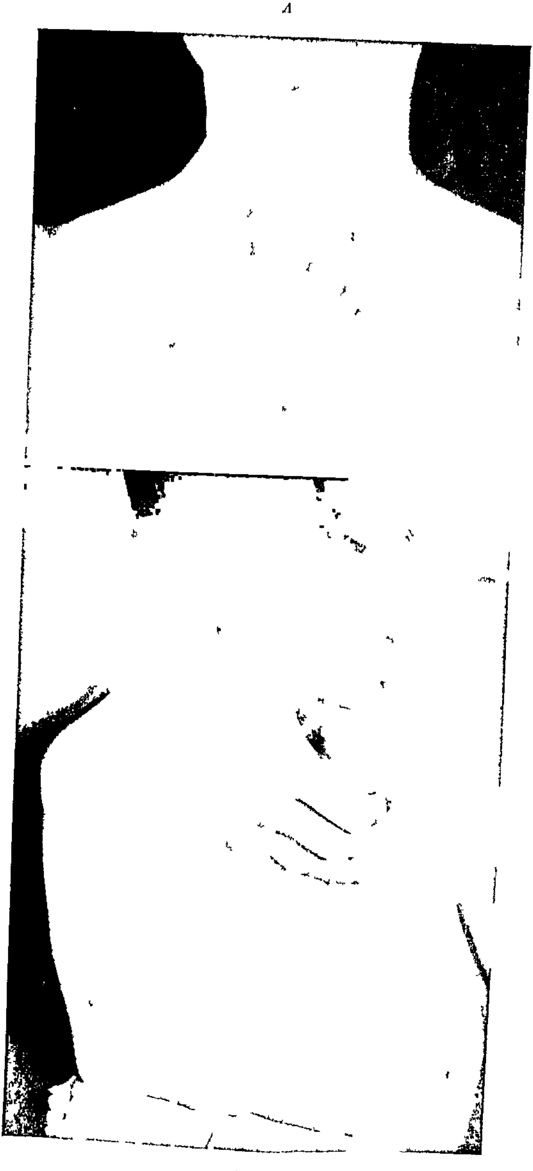

Fig 10.—*A* The left clavical scar one year after operation *B* The right thoracic year after operation

esophagus was delivered into the chest and mobilized with great ease. The utilization of the right chest offers the usual freedom for manipulation of the esophagus without interference from the arch of the aorta. It was found most satisfactory in the case herein reported, and the esophagus was mobilized and resected with ease.

The reconstruction of the esophageal defect always poses a problem, and the technique just described was chosen because of fear of bringing intra-remained in place and recent roentgenograms have revealed that swallowed food goes both through the polyethylene tube and around it. Attempts to remove the polyethylene tube through the oral approach have been unsuccessful because of failure of visualization. The polyethylene tube has not been successful in preventing contracture of the cervical anastomosis.

The medial portion of the left clavicle was removed in this instance because it was so badly damaged by previous x-ray therapy. It is not recommended that it be removed routinely because the operation can be performed without any intervention into the clavicle. The postoperative leakage at the anastomotic sites was possibly the result of the irradiation atrophy in the neck, but the case does demonstrate the well-known fact that healing will eventually occur if conservative measures are utilized.

The patient has remained well and apparently free of disease for almost two years after the initial resection. Because of a stricture at the sight of the superior anastomosis, an exploration of the pharynx and the fabricated esophagus was performed on May 1, 1956. No evidence of recurrent neoplasia was encountered. The new esophagus, made of a split-thickness skin flap, appeared healthy, moist and, except for a stricture at the site of the anastomosis, was patent throughout. The plastic tube was inferior to the clavicle and could not be removed by the cervical approach. A plastic repair of the stricture was effected.

SUMMARY

1. A case is reported of a carcinoma which involved a major segment of the esophagus. The possibility exists that this carcinoma could be the result of x-ray therapy which the patient received thirty-eight years ago.

2. The utilization of a left cervical approach and a right thoracic approach permitted resection of the major portion of the esophagus with relative ease.

3. The reconstruction of the defect by utilizing a split-thickness skin graft, supported by a polyethylene tube, and placed into the normal esophageal bed, was successful. The skin graft has apparently taken in its entirety.

4. The patient had leakage from both proximal and distal sites of anastomoses, which healed spontaneously. Drainage must be maintained for prolonged periods.

5. The patient, although apparently free of disease one year and nine months after resection, is suffering from contracture at the site of the cervical anastomosis which produces dysphagia. She is suffering from some dyspnea as a result of fibroses in the right chest, possibly secondary to the empyema necessitatis which developed subsequently to the first operation.

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RHABDOMYOSARCOMA OF THE ESOPHAGUS

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RHABDOMYOSARCOMA of the esophagus is an extremely rare tumor A search of the available bibliographic data has revealed only four previously reported tumors of this type in this location In 1950, Thorek and Neiman[5] reviewed the world literature and reported the first such tumor to be successfully resected surgically and the fourth to be recorded in the literature Credit for previous reported cases was given to Wolfensberger,[6] Glinski,[2] and Dvorak[1] in that report To the best of our knowledge, the present report is the second to record a successful esophageal resection for rhabdomyosarcoma

CASE REPORT

T R, a 54 year old Negro man, was admitted to the hospital on June 22, 1955 He was known to have ingested considerable quantities of alcohol over many years He had been hospitalized eight weeks previously and a diagnosis of pneumonitis had been made Response to antibiotic treatment was prompt, and he was discharged free of complaints after two weeks of hospitalization Approximately one week later he developed difficulty in swallowing solid foods The dysphagia advanced rapidly, but he was always able to take liquids In the ensuing five weeks he lost approximately 40 pounds His appetite was good, but only occasionally was he able to swallow soft food

Examination The examination was unremarkable His weight was 133 pounds There was evidence of marked weight loss The blood pressure was 128/70 Hg, pulse 80, and respirations 20 per minute There were no teeth in the upper jaw and those in the lower jaw were very poor No residual chest abnormalities were noted, no adenopathy was apparent, and the liver was not palpable

Laboratory Data Hemoglobin, 46 per cent, red blood count 2 6 million, white blood count, 8,700 with a normal differential The serum protein was reported as 10 Gm per cent, serum globulin 7 2 Gm, and albumin 2 8 Gm per 100 c c of serum The urine was reported negative for Bence Jones protein The blood urea nitrogen was 9 mg per cent and the fasting blood sugar was 98 mg per cent The prothrombin time was normal

An x ray study of the esophagus revealed considerable esophageal dilatation above a markedly irregular constriction situated just above the level of the diaphragm (Fig 1) Roentgenograms of the chest were negative Esophagoscopy was done and an irregular lesion was found which bled easily and was visualized 35 cm from the maxillary border Biopsy was performed and, upon microscopic examination, the pathologist reported a rhabdomyosarcoma

A plastic nasal feeding tube was passed into the stomach with little difficulty and a milk protein hydrolysate vitamin formula fed via the tube The daily caloric intake was 3,000 calories in approximately 3,000 c c of formula Within twelve days he had gained 9 pounds and felt much more energetic

Operation On July 7, 1955, thoracotomy was performed through the bed of the resected left eighth rib The lower esophagus was easily mobilized and found to contain

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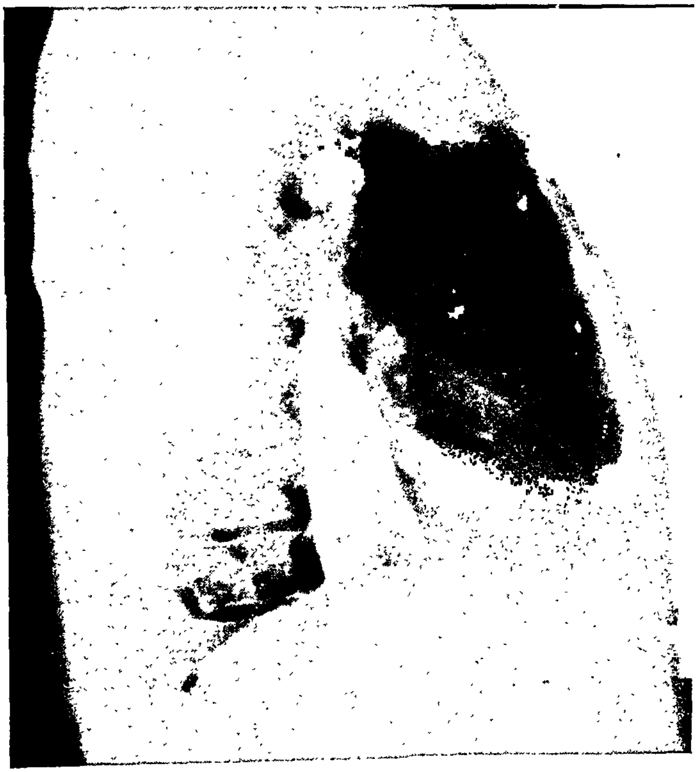
a tumor just above the level of the diaphragm (Fig. 2). The enlargement appeared fusiform with a grossly intact musculature. Palpation revealed that a lesion lay within the lumen which slipped up and down about 1 inch and which had its attachment on the right anterolateral aspect of the esophagus. In the region of attachment, a thickening within the musculature of the esophagus was apparent on palpation. Because of the histologic appearance of the biopsy specimen taken previously, a resection was deemed advisable.



g. 1.—Roentgenogram of lateral view of chest showing defect in distal esophagus on barium-swallowing function.

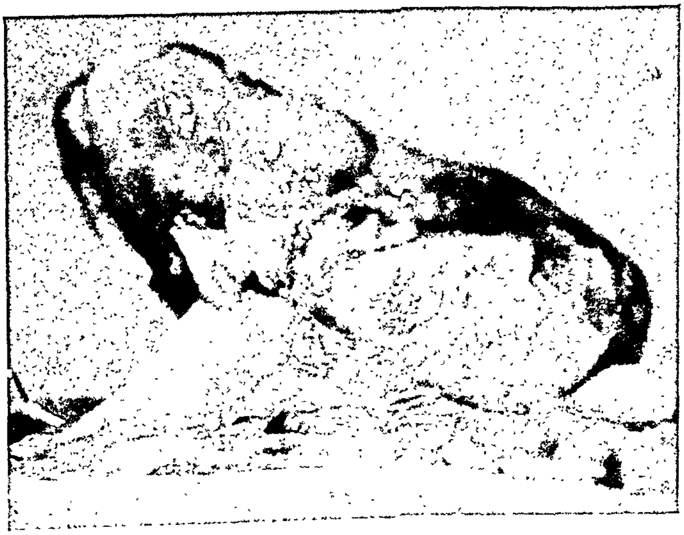


Fig. 2.—Profile view of tumor in opened specimen.

The diaphragm was opened through the dome, and palpation of the contents of the peritoneal cavity was negative except for the presence of two small, firm, globular nodules in the superior aspect of the right lobe of the liver. Because of the approach, direct inspection of these lesions was not possible. Whether they represented metastatic lesions remains to be determined.

The stomach was mobilized superiorly by dividing gastrocolic omentum and left gastric artery on greater and lesser curvatures, respectively. The stomach was then divided to include the upper one fourth in the resected specimen, closed on the lesser curvature aspect, and anastomosed to the esophagus at a level about 4 cm above the lesion. The diaphragm was repaired, and the chest was drained through a single tube placed posterolaterally. Water seal drainage was applied. The chest was closed.

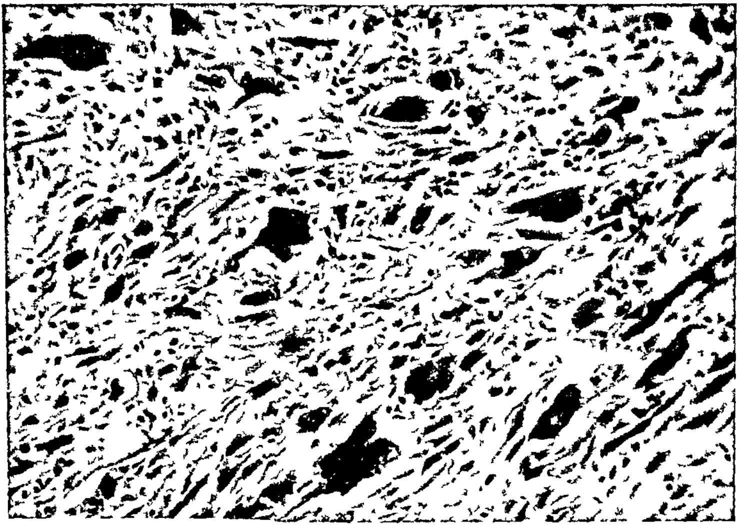


Fig. 3.—High power photomicrograph of lesion (×290, reduced ¼).

The Levin tube which had been placed into the gastric remnant was inadvertently withdrawn when the endotracheal tube was removed. It was not replaced.

The patient was allowed fluids by mouth on the sixth postoperative day, and solid food was given on the ninth postoperative day. His convalescence was entirely uneventful, and he was discharged on July 26, 1955, the nineteenth postoperative day.

Pathology Report.—Gross Specimen. The specimen consisted of the lower end of the esophagus and a small portion of the cardiac end of the stomach. Approximately 7 cm of esophagus was included and the stomach measured 3 cm along the lesser curvature. Attached to the portion of the esophagus and extending to within approximately 1.8 cm of the upper margin there was a cylindrical mass measuring 10.4 cm in length and 4.7 cm in diameter. This was firm and fleshy. The surface was mottled red and purple. At one side there was an area of irregular fungating yellowish tissue which had extended through the capsule. Areas showed some infiltration into the wall of the esophagus as well as what appeared to be a few small satellite nodules. The mass was attached by a broad pedicle measuring approximately 5.5 by 3.5 cm. It caused a bulge in the outer surface of the esophagus but grossly did not extend through. Cross sections through the mass revealed a firm, yellow tumor which retracted from the cut surface. The tumor was fleshy in consistency and had a typical fish-flesh appearance. On sections through the posterior surface, it was seen to extend through the wall of the esophagus and to be covered only by a thin membrane.

Microscopic: (Fig. 3.) Sections of the tumor mass showed the same bizarre appearance and the same grotesque histology as was seen in the biopsy. Many of the cells were elongated and straplike with a tendency to be arranged in parallel groups. However, this tendency was not marked. In addition, there were numerous grotesque tumor giant cells. These typically had extremely large and hyperchromatic nuclei which showed tremendous variation in size and shape. They were frequently lobulated. They showed coarse clumping of chromatin and tremendous karyosomes. Many of the bizarre cells showed the abundant cytoplasm to be divided into parallel, fine beaded fibrils. There was superficial ulceration of the tumor, and the tumor was seen to extend throughout the depth of the wall. The serosal covering mentioned previously was imperfect. In addition, a very tiny area of firmness that was found within the adjacent fat, was found to be a portion of the tumor. There was irregular invasion of adjacent fat. Phosphotungstic acid stains were prepared, but cross striations were not convincingly demonstrated.

Diagnosis: Rhabdomyosarcoma.

DISCUSSION

Explanation for the occurrence of a malignant striated muscle tumor in an area consisting of smooth muscle has been attempted by Thorek and Neiman.[5] The presence of an embryonic rest or metaplasia were possibilities advanced by these authors. Whether or not such an explanation need be advanced in their case is questionable. The lesion described by them occurred in the mid-esophagus where striated and smooth muscle cells are said to coexist.[3, 4] In the case herein reported, such an explanation seems reasonable.

SUMMARY

A case of rhabdomyosarcoma of the esophagus resected surgically with survival of the patient is reported. We believe it to be the fifth such tumor recorded in the medical literature and the second to be successfully resected.

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POSTEROANTERIOR CHEST ROENTGENOGRAM IN TWO TYPES OF ANOMALOUS PULMONARY VENOUS CONNECTION

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It has been said that conventional roentgenology contributes only about 10 per cent toward the diagnosis of heart disease. No doubt, this figure is in many cases an overestimation. But, on the other hand, there are certain types of cardiovascular malformations in which routine methods of roentgenology can contribute about 100 per cent toward the anatomic diagnosis. Reference is specifically made, in this communication, to the two types of anomalous connection of the pulmonary veins that can be diagnosed from the routine posteroanterior chest roentgenogram. These two types are:

1. The type in which all of the blood of both lungs drains to the right superior vena cava by a partially persistent left superior vena cava or left vertical vein. This is the so-called figure-of-eight type or "cottage-loaf"[9] type of total anomalous pulmonary venous connection. About 30 cases of this condition have now been described in the literature,[4-10] the majority in the last three years.

2. The type in which part or all of the blood from the right lung drains into the inferior vena cava. Fewer cases of this type have been described,[1-3, 7] probably owing partly to the fact that the roentgenogram is not as spectacular as that of the figure-of-eight type, and the abnormality is more easily overlooked.

Several cases of each type are described in this communication, the main reasons being to add these cases to a not as yet overburdened literature, as well as to draw the attention of those not familiar with these lesions to a very fascinating group of cases. The value of the posteroanterior roentgenogram is stressed in the diagnosis of these conditions, and the spectacular use to which tomography can be put in demonstrating the right anomalous pulmonary veins is illustrated. No attempt is made to discuss the interesting catheterization data provided by these cases.

FIGURE-OF-EIGHT TYPE OF TOTAL ANOMALOUS PULMONARY VENOUS CONNECTION

The term "anomalous pulmonary venous *connection*" is used to differentiate the state of affairs when pulmonary veins are normally connected with

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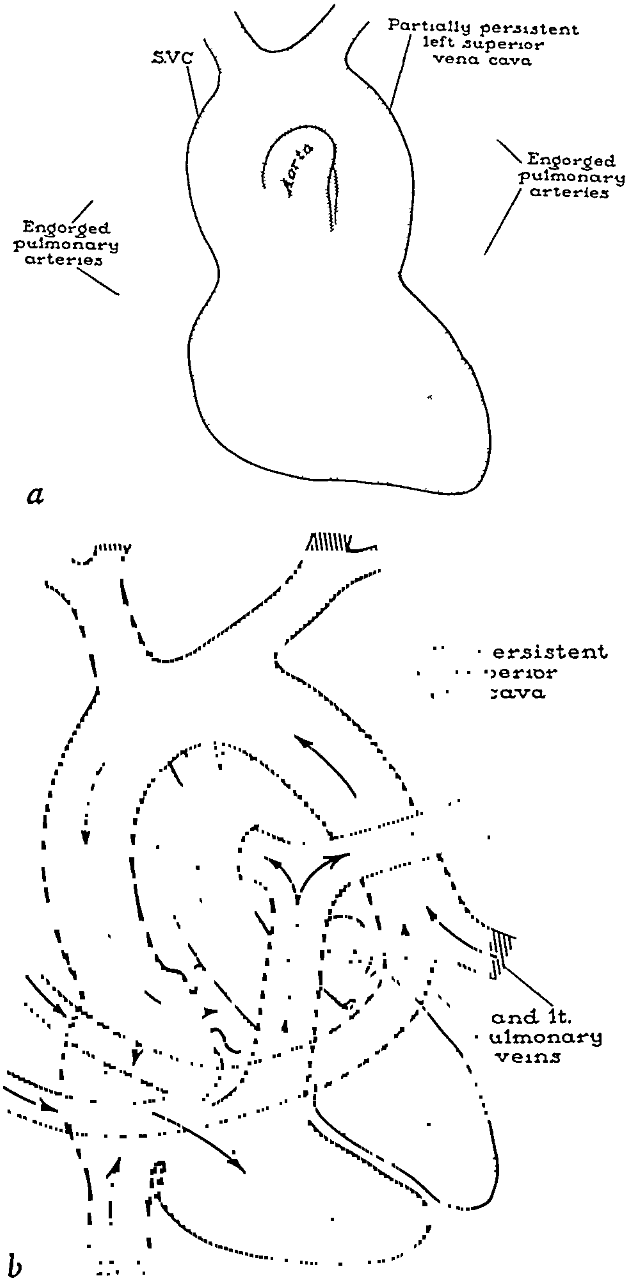
the heart but *drain abnormally* (for example, preferential drainage of the right pulmonary veins to the right atrium through an atrial septal defect).

The two diagrams in Fig. 1 illustrate the general anatomy of the venous anomaly in this type of case.


S.V.C
Aorta
Partially persistent left superior vena cava
Engorged pulmonary arteries
Engorged pulmonary arteries
a
ersistent
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1.—Diagrams explaining (*a*) the roentgenographic appearance, and (*b*) circulatory anatomy in the figure-of-eight type of total anomalous pulmonary venous connection.

It is obvious that if there is no atrial septal defect, the condition is in- patible with life for more than a short while. If an atrial septal defect resent but not of sufficient size, life is in danger owing to the large burden on the right ventricle. In these cases the lung fields will probably show marked engorgement, since the systemic and most of the pulmonary venous blood will recirculate through the lungs. If the shunt from the right to the left atrium is large, there will be an equitable sharing of blood between the two ventricles. It is probable that this is the situation in those patients who have relatively little difficulty. Theoretically then, the less difficulty these patients have, the more normal should the peripheral pulmonary vascularity appear, while the more trouble they have, the more engorged will be the appearance of the lung fields.

The roentgenologic finding par excellence in these cases is the figure of eight configuration of the cardiac silhouette, as is explained in Fig. 1. Fluoroscopically, the upper part of this shadow, which is composed of the left and right superior venae cavae, will show a gentle pulsation, whereas the pulmonary trunk and its branches may show considerable exaggeration of pulsation as compared to normal.

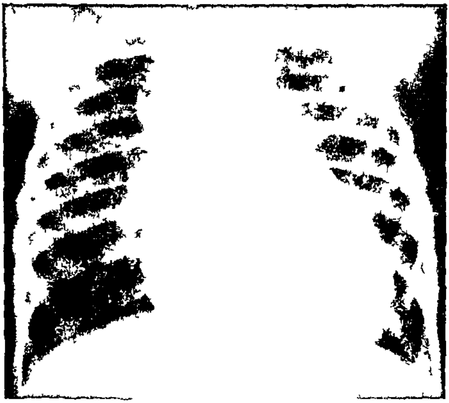

Fig. 2.—Case 1. Figure of eight type of total anomalous pulmonary venous connection in a boy aged 3 years. Note the bilateral mediastinal widening.

CASE 1.—A boy, aged 3 years, had suffered from "heart trouble" since birth. The child was blue for the first few days, and after that the mother noted blueness of his hands and feet when she gave him a bath. In the newborn period, bilateral inguinal hernias developed, and a right herniorrhaphy was attempted at 4 months of age. The child was said to have "passed out" on the operating table. At this time a murmur was first noted. The child would fatigue easily and on some days was breathless all the time. He squatted frequently.

On examination there was slight cyanosis of the hands and feet, and the cardiologist reported a moderate systolic murmur, maximal in the midprecordial area, well heard toward the apex but not in the left subclavicular area.

A chest roentgenogram (Fig. 2) showed a rounded shadow projecting on each side of the superior mediastinum, the appearance being suggestive of the figure of eight sign. Fluoroscopically, pulsations of pulmonary vessels did not appear abnormal.

the right and the left atrium, the lung fields on the roentgenogram would appear normal, that is, the pulmonary vessels would not appear engorged. If, however, there is some reason, such as, for instance, an atrial septal defect that is too small, or some other factor that causes a larger amount of blood to pass through the right side of the heart than through the left side, then one would expect pulmonary vascular engorgement. It is probable that in all such cases the condition will proceed eventually to pulmonary hypertension and increasing cyanosis. Furthermore, the greater the obstruction to an initial right-to-left flow at the atrial level (small atrial septal defect or patent foramen ovale), the bigger the patient's problem becomes, as the right side of the heart becomes overloaded, the lungs tend to "drown," and the systemic circulation is deprived of blood; in the extreme case, in which no communication exists between the atrial chambers, life is of course impossible.

CASE 4.—In 1951, a woman, aged 52 years, came to the Clinic because of backache, abdominal discomfort, burning on urination, and some frequency. Most of these complaints dated since a hysterectomy in 1950. She stated during the examination that she had been a blue baby, and that she suffered from dyspnea on mild exertion. Her blood pressure was approximately 90 mm. Hg systolic and 60 diastolic, the heart rate was 68 beats per minute and the rhythm was regular. It was noted that there was a harsh systolic murmur over the precordium. There were slight clubbing of the fingers and toes and cyanotic mottling of the hands and feet. The blood count showed secondary polycythemia, which was considered to be due to a congenital heart condition. The electrocardiogram showed right axis deviation. A chest roentgenogram and fluoroscopy showed a bilateral upper mediastinal widening, and there was thought to be some increased prominence of the pulmonary vascular markings. Pulsations of the pulmonary vessels were not considered to be abnormal. The mediastinal shadow was noted to have a quiet expansile pulsation, and it was thought that the shadow might be that of a smoothly dilated aorta.

In reviewing a group of films recently, my colleagues and I came across the chest roentgenograms of this patient (Fig. 5), and the probability of total anomalous pulmonary venous connection was suspected. Inquiries were therefore made about the patient and it was learned that she had undergone cardiac catheterization in 1953, at which time the essential findings were as follows: the superior vena cava was widened, with evidence of arterialization in it; the left side of the mediastinal shadow was found to be due to an anomalous vein (presumably the common pulmonary vein leading to the left innominate vein); there was marked pulmonary hypertension; identical systolic pressures were found in the pulmonary artery, right ventricle, and brachial artery. Although these findings were considered to be evidence for a ventricular septal defect, and although this may be the case, they may also be the result of the marked pulmonary hypertension, the cyanosis occurring by a right-to-left shunt at the atrial level, an interatrial communication apparently being the more common finding in cases of total anomalous pulmonary venous connection.

This patient returned to the Clinic in April, 1955. She was found to be severely disabled by fatigue and dyspnea. On exercise in the laboratory with an ear oximeter in place, the percentage oxygen saturations were found to be: 76 per cent at rest; 40 per cent after 2 minutes' exercise on the treadmill, and 84 per cent after breathing 100 per cent oxygen for twelve minutes.

However, she felt that her disability was not sufficient to justify further catheterization or surgical correction at this time, and she returned home.

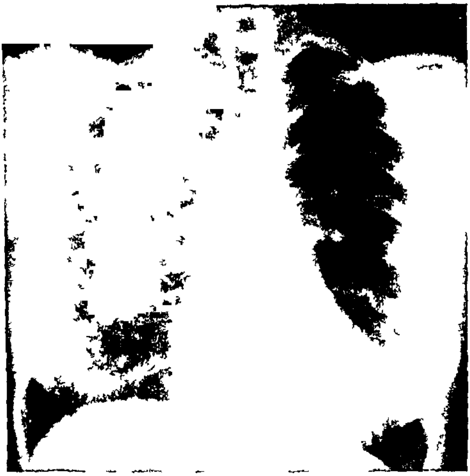

Fig. 5.—Case 4. Posteroanterior roentgenogram showing typical figure of eight configuration of the cardiovascular shadow in the type of total anomalous pulmonary venous connection under discussion. Note also the pulmonary vascular engorgement.

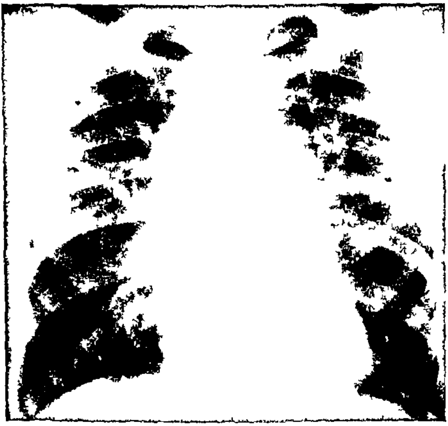

Fig. 6.—Case 5. The appearance of the cardiovascular shadow on this posteroanterior chest roentgenogram is characteristic of the figure of eight type of total anomalous pulmonary venous connection. Note also engorged pulmonary arteries.

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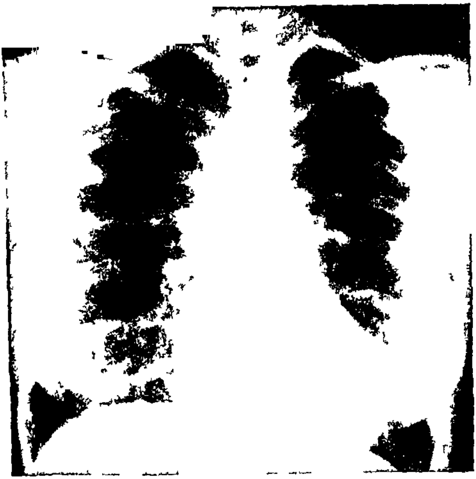

Fig. 5.—Case 4. Posteroanterior roentgenogram showing typical figure of eight configuration of the cardiovascular shadow in the type of total anomalous pulmonary venous connection under discussion. Note also the pulmonary vascular engorgement.

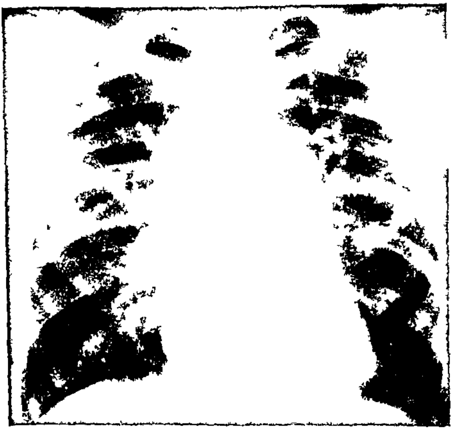

Fig. 6.—Case 5. The appearance of the cardiovascular shadow on this posteroanterior chest roentgenogram is characteristic of the figure of eight type of total anomalous pulmonary venous connection. Note also engorged pulmonary arteries.

This patient returned to the Clinic in January, 1956, and underwent cardiac catheterization. The findings were typical for the figure-of-eight total anomalous pulmonary venous connection with an atrial septal defect and severe pulmonary hypertension.

Comment.—This case is of interest in that the patient is by far the oldest living patient with this type of pulmonary venous anomaly to be described. In other respects her condition does not differ from that of the other patients whose cases are presented.

CASE 5.—A man, aged 18 years, entered the Clinic on Dec. 8, 1947, for consultation regarding a "tumor of the chest" which had been discovered when he tried to enlist in the Army two months previously. To his knowledge he had had no chest symptoms excepting some hemoptysis during the last six months. One month prior to his visiting the Clinic there had been an episode suggesting right hemiparesis with dizziness and inability to recognize anyone for a few days. He recovered completely in a few weeks and was feeling fine. A chest roentgenogram (Fig. 6) showed a bilateral superior mediastinal widening which on fluoroscopy was thought to be vascular. The branches of the pulmonary arteries in the lung fields were exaggerated and showed vigorous pulsation. An angiocardiogram was taken but the result was unsatisfactory. An electrocardiogram was interpreted as showing right ventricular hypertrophy. Atrial septal defect was considered, and it was thought that the hemiplegia might have been the result of a paradoxical embolism. A systolic murmur was heard in the third left interspace.

Although the diagnosis of an atrial septal defect seemed certain, the question of whether the superior mediastinal shadow was solid or vascular was not yet settled, and an exploratory operation was resorted to on Jan. 6, 1948. In the anterior mediastinum a large, ovoid, blue "mass" was found. It extended upward to the subclavian vein adjacent to the subclavian artery, overlay the arch of the aorta, and descended to the hilus of the lung anteriorly. It was tense and thin-walled, and blood could be seen swirling through it. Two vessels, apparently the two branches of the superior pulmonary vein on the left, entered this large vascular lesion. The pulmonary artery was twice as large as usual but was in the normal location.

The operation was terminated, and the patient recovered uneventfully.

Comment.—It seems, in the light of more recent knowledge about anomalous pulmonary venous return, that this patient almost certainly suffers from the "figure-of-eight" type of total anomalous venous connection. We have knowledge that this patient was still living in 1954, but do not know his clinical status.

Sepulveda and associates have presented a case of this type with a somewhat similar clinical picture: a woman, aged 42 years, who had at one time had roentgen treatment for a superior mediastinal "mass," and who also had had an episode of hemiplegia at the age of 28 years.

ANOMALOUS RIGHT PULMONARY VEIN

When most or all of the right lung drains into the inferior vena cava close to the region where the latter enters the right atrium (Fig. 7), various characteristic roentgenologic features may be seen to make one suspect the presence of this situation.

1. The anomalous vein can frequently be distinguished close to the right cardiac border. Near the diaphragm it becomes a single trunk, having collected branches from as high as the apex of the right lung. Invariably this vein can be beautifully demonstrated by tomographs.

2. Usually the heart will present prominently into the right hemithorax, and this is probably a reflection of an enlarged right atrium, this chamber receiving considerably more blood than it normally does. However, in certain cases it has been shown that this venous anomaly is accompanied by hypogenesis of the right lung, and in such cases it may be natural for the heart to be shifted to varying degrees into the right hemithorax.

3. It is not known in what percentage of these cases there are atrial septal defects. Of those patients who have been catheterized at the Mayo Clinic, one has had an atrial septal defect, while the other did not have the additional lesion. Judged by the appearance of the lung fields and the absence of clinical findings, it would seem that in the majority of cases there is not an atrial septal defect.

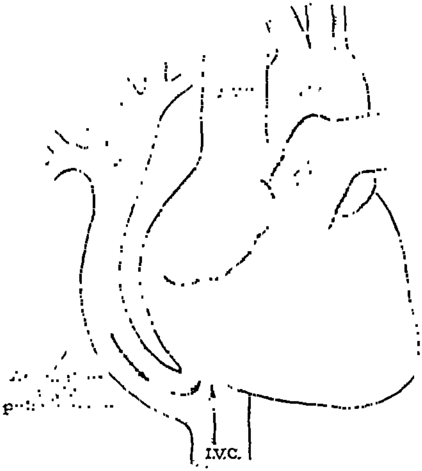

Fig. 7.—Diagram explaining the roentgen anatomy of the cases of anomalous venous connection of the right lung.

Case 6.—A woman, aged 43 years, entered the Clinic because of a variety of complaints probably unrelated to her cardiac defect. Attention was drawn to the circulatory abnormality because the routine thoracic roentgenogram showed that the heart was predominantly in the right half of the thorax. The heart sounds were heard best to the right of the sternum; no murmurs were present. The physical examination otherwise showed no abnormal findings.

The thoracic roentgenogram was interpreted as probably indicative of agenesis of a portion of the right lung, with a large aberrant vessel in the basal portion of the right lung (Fig. 8, *a*). The anomalous vessel is well seen on the tomogram (Fig. 8, *b*). The trachea was situated to the right of the midline. The electrocardiogram was considered normal except that the precordial leads reflected the displaced position of the heart, with unusually high R waves in leads taken to the right of the sternum. At bronchoscopy it was noted that the patient had a very peculiar distribution of the bronchi of the right lung. It was first noted that the carina, instead of being in the anteroposterior direction, was rotated clockwise so that the upper border was pointed at about 2 o'clock, while the lower was pointed in the neighborhood of 7 o'clock. The openings to the various branches of the right lower lobe were very wide and not in their normal position. The picture resembles that frequently seen associated with a bronchus going into a cystic area of the lung. The left side appeared perfectly normal.

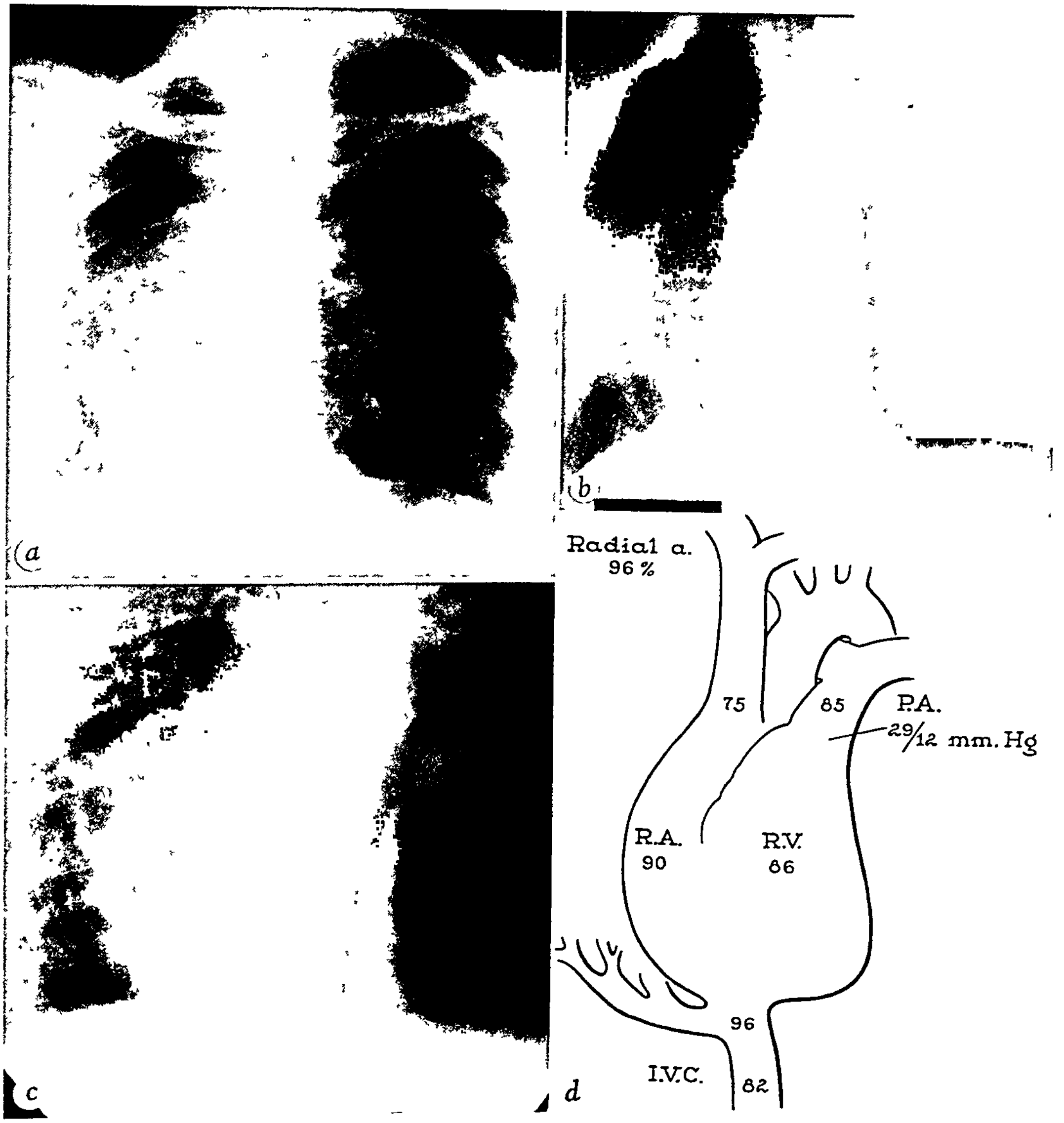

Fig. 8.—Case 6. *a,* Posteroanterior roentgenogram of a woman, aged 43 years, who has anomalous pulmonary drainage of the right lung to the inferior vena cava. Note the displacement of the heart into the right hemithorax; the anomalous vein can be detected through the heart shadow. *b,* A tomogram of this case demonstrates the anomalous vein very well. *c,* The tip of the cardiac catheter lies in the right pulmonary artery. An injection of Urokon sodium has been made, and the anomalous right pulmonary vein is beautifully demonstrated. *d,* Schematic representation demonstrating oxygen saturations found at various levels in the central circulation in Case 6.

A bronchogram was performed and revealed the left lung to be well developed; all bronchial segments could be identified. On the right side the upper lobe bronchus was seen for a distance of 1.5 cm., where it abruptly terminated. It appeared to be of larger caliber than normal. All of the segmental bronchi of the right middle lobe and right lower lobe could be identified The right main bronchus was pulled upward and somewhat posteriorly, and the right middle lobe appeared to supply the apex of the right thorax Atelectasis or agenesis of the right upper lobe was diagnosed

The main abnormality on cardiac catheterization was the high oxygen saturation of blood in the inferior vena cava at the diaphragmatic level Blood of low oxygen saturation was obtained when the catheter was advanced slightly distally in the inferior vena cava With the catheter in the right main pulmonary artery a 70 per cent solution of sodium acetrizoate (Urokon sodium) was injected into the artery, this medium rapidly outlined the anomalous right pulmonary vein coursing toward the inferior vena cava (Fig 8, c)

A schematic representation of the central circulation in this patient illustrates the oxygen saturation of samples of blood taken from various sites within the heart and great vessels with the patient breathing room air (Fig 8, *d*) The systemic arterial oxygen saturation was 96 per cent The catheter could not be passed into the anomalous right pulmonary vein The calculated recirculation was 30 per cent, expressed as the percentage of pulmonary flow that returned to the right side of the heart from the right lung This correlates moderately well with the size of the right lung, approximately one half of which was absent, as judged by bronchography

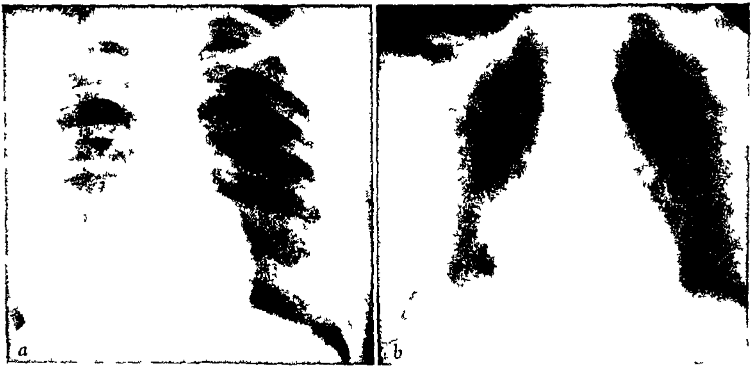

Fig 9 —Case 7 *a* The streaky appearance of the vessels along the right border of the heart and the slight shift of the heart into the right hemithorax suggest that further study should be done to exclude an anomalous vein in the right base *b* The tomogram confirms the presence of a large anomalous vessel in the right base probably an anomalous vein draining the right lung

CASE 7 —A woman, aged 26 years, came to the Clinic because of a question of pregnancy as well as the possibility of a congenital heart lesion A chest roentgenogram (Fig 9, *a*) revealed possible anomalous venous connection of the right lung, and tomograms (Fig 9, *b*) confirmed the suspicion of a large anomalous vessel draining toward the inferior vena cava The heart also projected more into the right hemithorax than it normally would, probably as the result of enlargement of the right atrium, but possibly also owing to hypogenesis of the right lung Clinically, the right upper thorax was depressed and probably somewhat smaller than the left A cardiologist evaluated the patient's cardiologic status with respect to the possibility of termination of pregnancy There was not enough evidence of cardiac disability to justify such a measure, and the patient was advised to return after the birth of her child, for catheterization studies and possibly for a corrective operation rotated clockwise so that the upper border was pointed at about 2 o'clock, while the lower was pointed in the neighborhood of 7 o'clock. The openings to the various branches of the right lower lobe were very wide and not in their normal position. The picture resembles that frequently seen associated with a bronchus going into a cystic area of the lung. The left side appeared perfectly normal.

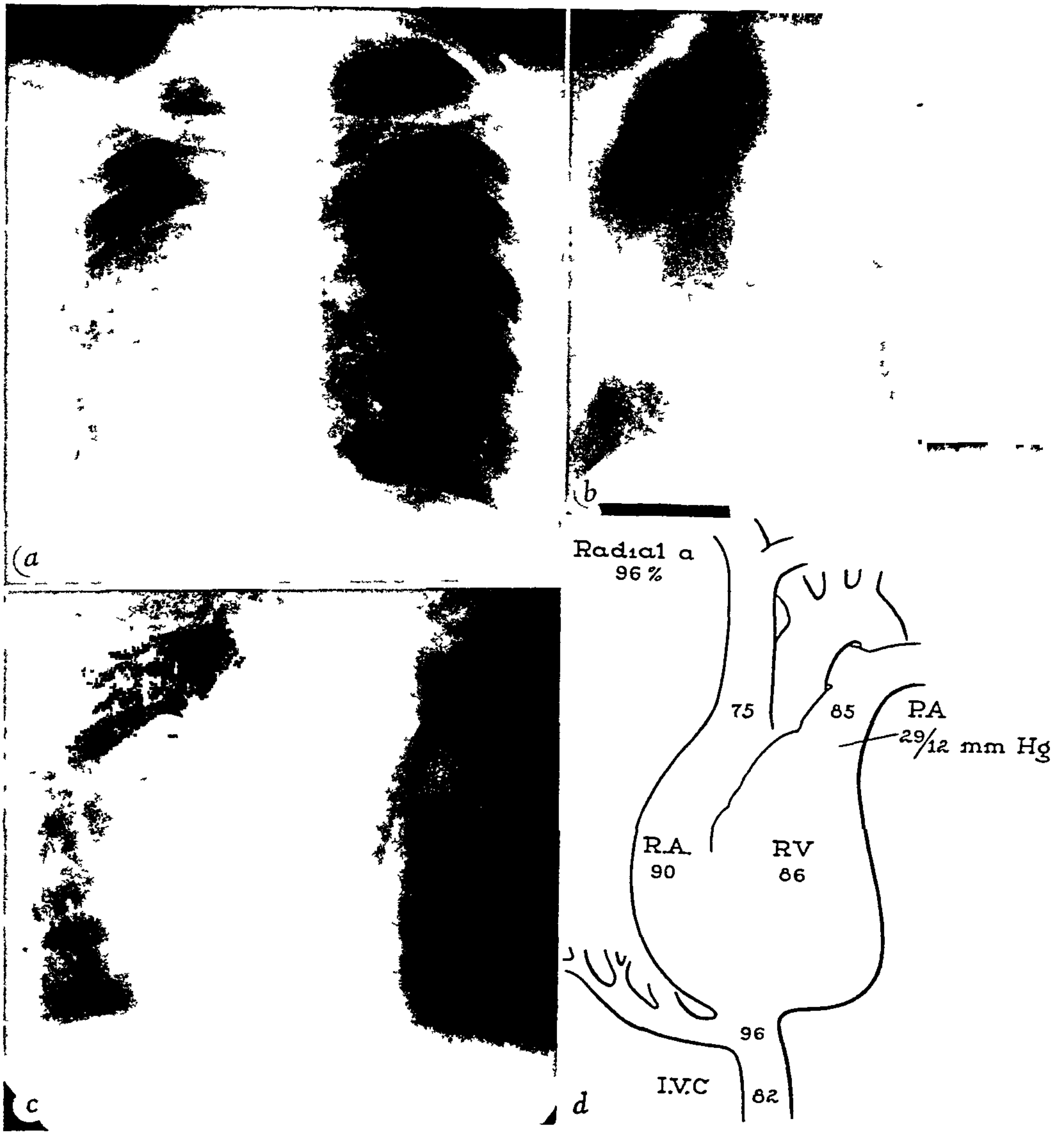

Fig 8—Case 6 *a*, Posteroanterior roentgenogram of a woman, aged 43 years, who has anomalous pulmonary drainage of the right lung to the inferior vena cava Note the displacement of the heart into the right hemithorax, the anomalous vein can be detected through the heart shadow. *b*, A tomogram of this case demonstrates the anomalous vein very well *c*, The tip of the cardiac catheter lies in the right pulmonary artery. An injection of Urokon sodium has been made, and the anomalous right pulmonary vein is beautifully demonstrated *d*, Schematic representation demonstrating oxygen saturations found at various levels in the central circulation in Case 6

A bronchogram was performed and revealed the left lung to be well developed; all bronchial segments could be identified. On the right side the upper lobe bronchus was seen for a distance of 1.5 cm., where it abruptly terminated. It appeared to be of larger caliber than normal. All of the segmental bronchi of the right middle lobe and right lower lobe could be identified. The right main bronchus was pulled upward and somewhat posteriorly, and the right middle lobe appeared to supply the apex of the right thorax. Atelectasis or agenesis of the right upper lobe was diagnosed.

The main abnormality on cardiac catheterization was the high oxygen saturation of blood in the inferior vena cava at the diaphragmatic level. Blood of low oxygen saturation was obtained when the catheter was advanced slightly distally in the inferior vena cava. With the catheter in the right main pulmonary artery a 70 per cent solution of sodium acetrizoate (Urokon sodium) was injected into the artery; this medium rapidly outlined the anomalous right pulmonary vein coursing toward the inferior vena cava (Fig. 8, *c*).

A schematic representation of the central circulation in this patient illustrates the oxygen saturation of samples of blood taken from various sites within the heart and great vessels with the patient breathing room air (Fig. 8, *d*). The systemic arterial oxygen saturation was 96 per cent. The catheter could not be passed into the anomalous right pulmonary vein. The calculated recirculation was 30 per cent, expressed as the percentage of pulmonary flow that returned to the right side of the heart from the right lung. This correlates moderately well with the size of the right lung, approximately one half of which was absent, as judged by bronchography.

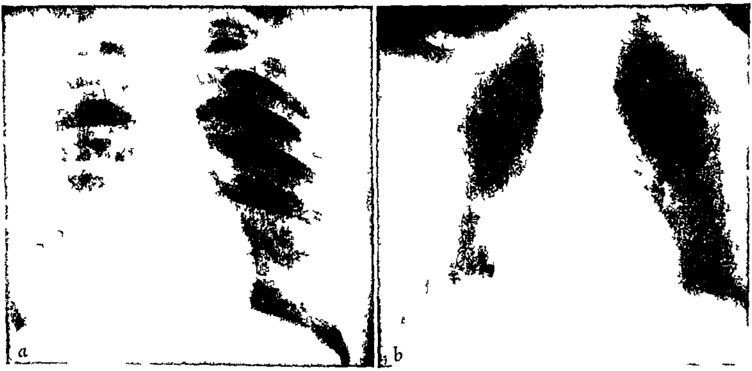

Fig. 9.—Case 7. *a*, The streaky appearance of the vessels along the right border of the heart and the slight shift of the heart into the right hemithorax suggest that further study should be done to exclude an anomalous vein in the right base. *b*, The tomogram confirms the presence of a large anomalous vessel in the right base, probably an anomalous vein draining the right lung.

CASE 7.—A woman, aged 26 years, came to the Clinic because of a question of pregnancy as well as the possibility of a congenital heart lesion. A chest roentgenogram (Fig. 9, *a*) revealed possible anomalous venous connection of the right lung and tomograms (Fig. 9, *b*) confirmed the suspicion of a large anomalous vessel draining toward the inferior vena cava. The heart also projected more into the right hemithorax than it normally would, probably as the result of enlargement of the right atrium, but possibly also owing to hypogenesis of the right lung. Clinically, the right upper thorax was depressed and probably somewhat smaller than the left. A cardiologist evaluated the patient's cardiologic status with respect to the possibility of termination of pregnancy. There was not enough evidence of cardiac disability to justify such a measure, and the patient was advised to return after the birth of her child, for catheterization studies and possibly for a corrective operation.

CASE 8.—A girl, aged 11 years, was brought to the Clinic because of mental retardation. The routine chest roentgenogram was suggestive of an anomalous vessel in the right lung (Fig. 10, *a*). Tomograms confirmed this impression (Fig. 10, *b*) and suggested that the vessel drained toward the inferior vena cava. This patient had not had any pulmonary symptoms, and the cardiologist could not obtain any evidence of cardiac disability.

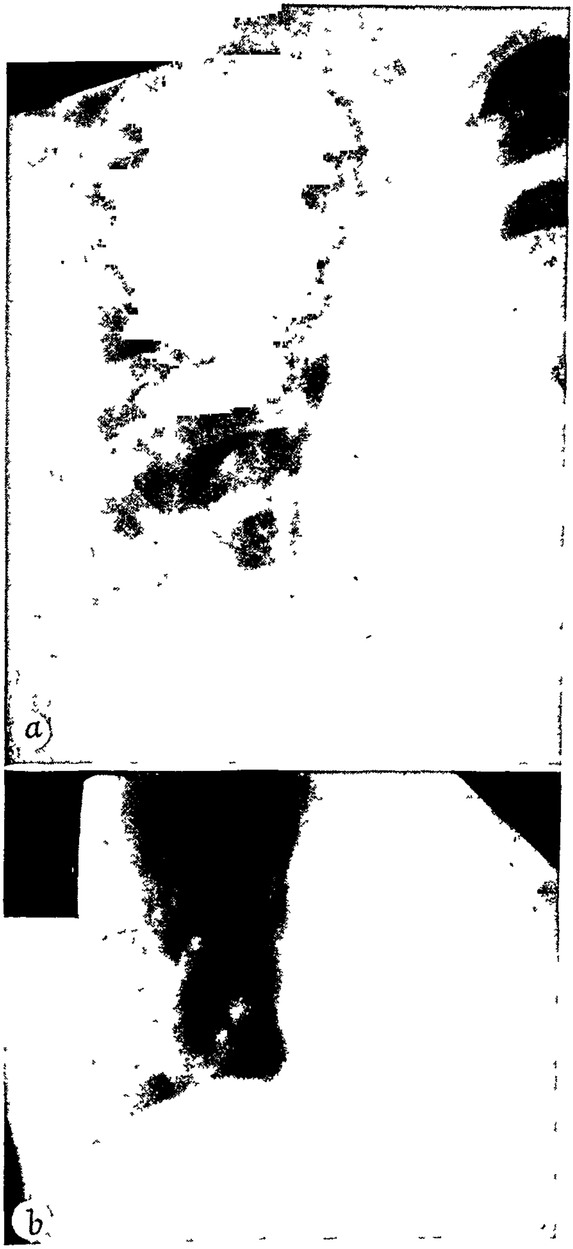

Fig. 10.—Case 8. *a*, Portion of posteroanterior chest roentgenogram of a girl, aged 11 years, showing anomalous vessel in the right base. *b*, The tomogram shows the anomalous vessel more clearly.

Comment.—In this case it was not possible to obtain catheterization studies or angiocardiography, so that the only "proof" of an anomalous venous connection of the right lung lies in the appearance of the roentgenogram and the fact that no other condition is known to cause this appearance.

CASE 9.—A woman, aged 53 years, accompanied a friend of hers to the Clinic and decided also to have a general examination. She had at times suffered from bronchitis, but had no specific or serious complaints. The results of her general examination were negative except that the chest roentgenogram revealed the presence of a large anomalous vessel on the right (Fig. 11, *a*), apparently an anomalous vein draining the blood from the right lung into the inferior vena cava near its entrance into the right atrium. This interpretation was confirmed by a tomogram (Fig. 11, *b*). The significance of the lesion, in the event of the occurrence of any future pathologic process of the left lung, was explained to the patient. She decided against an extensive cardiovascular investigation at the present time.

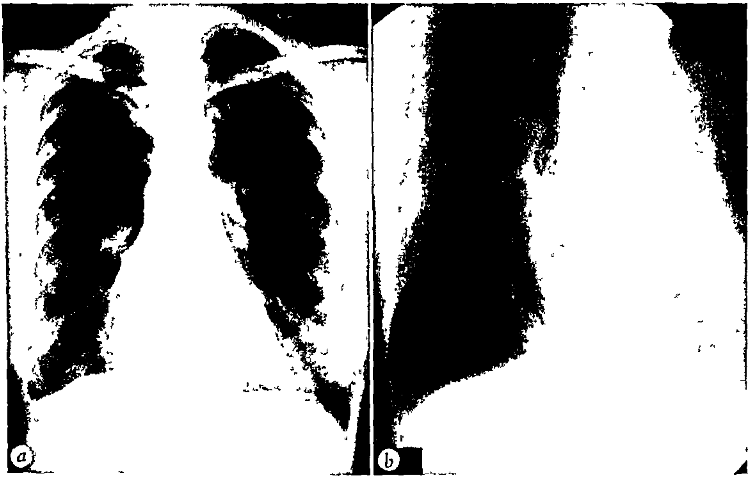

FIG. 11.—Case 9. *a*, Posteroanterior chest roentgenogram showing abnormal right paracardiac shadow which is due to an anomalous pulmonary vessel. There is also slight prominence of the heart in the region of the right atrium. *b*, Tomogram of the right lower portion of the chest clearly demonstrates the anomalous pulmonary vein, which drains toward the area where the inferior vena cava joins the right atrium.

CASE 10.—A woman, aged 43 years, had first been to the Clinic in 1926, at which time she had undergone tonsillectomy as well as an operation on the nose. In 1947, a cystadenocarcinoma of one of her ovaries had been removed elsewhere. She came to the Clinic later in 1947 and again in 1949 for postoperative evaluation. Her condition was satisfactory, and no evidence of recurrence could be detected. In 1931, a roentgenologist had remarked that the heart was rotated and displaced to the right. In 1947 the possibility of congenital heart disease was mentioned by the roentgenologist.

In 1952, she returned to the Clinic since she was nervous about a possible recurrence of the cystadenocarcinoma, but no such evidence could be found. At this time the roentgenologist remarked on what appeared to be an abnormal vessel in the right lung (Fig. 12). In 1954, this shadow was again noted, and anomalous venous connection of the right lung to the inferior vena cava was suggested. The cardiologist could find no evidence of significant heart disease at this time, and the patient did not want to remain for further cardiovascular studies.

Comment.—The roentgenologic findings in this case are similar to those in cases previously described in the literature. Although physiologic proof is lacking, it would be surprising if this were not a case in which anomalous venous connection of the right lung to the inferior vena cava existed.

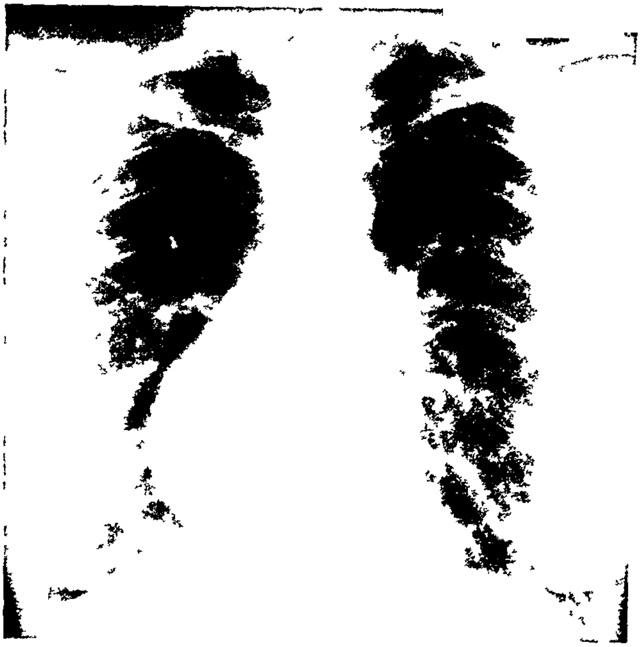

Fig 12—Case 10. Posteroanterior chest roentgenogram illustrates the large anomalous vessel in the right lower portion of the chest, which is undoubtedly an anomalous right pulmonary vein draining into the inferior vena cava As a result of this the right atrium is larger than normal, and projects into the right side of the chest farther than it normally would

COMMENT

In a paper on total anomalous pulmonary venous drainage, Whitaker reported on 6 cases, 3 of which were found early in 1953, and he remarked that this "suggests that this anomaly is not so rare as the published cases indicate. When it is widely known that the radiological features are sufficiently characteristic to allow the anomaly to be recognized at routine examination there will probably be an increase in the frequency of its diagnosis. . . ." There seems to be considerable truth in this statement. The patients having total anomalous connection on whom data are presented in this communication were all examined, or re-examined in view of recent knowledge, within the last year. Undoubtedly there are other cases in our files which have been regarded as tortuosity of the aorta or a mediastinal mass. We have made no attempt to unearth them.

It is of interest from the point of view of differential diagnosis that, in a child, the thymus may cause a shadow on the posteroanterior chest roentgenogram which is identical with the figure-of-eight picture. The lateral view is probably of differential diagnostic value, for in the cases of total anomalous venous connection that my colleagues and I have seen, the anterior mediastinum has been clear, whereas if an "abnormal" shadow is due to the thymus, the anterior mediastinum will not be clear.

Furthermore, although theoretically a case of total anomalous venous connection (in which there is optimal division of blood at the atrial level) may show normal vascular markings, in practice all the roentgenograms of patients that we have seen have shown evidence of vascular engorgement such as is seen in cases of recirculation. For the present, therefore, increase in the peripheral pulmonary arterial markings should be regarded as an essential part of the roentgenologic diagnosis.

It is of interest that in all the cases in our group in which there were adequate physiologic data there has been marked pulmonary hypertension. In view of newer techniques in surgery, it therefore behooves the roentgenologist to be familiar with this condition, since it is potentially correctable, and probably preferably so in the younger years of life.

With respect to the cases presented in this paper as anomalous venous connection of part or all of the right lung to the inferior vena cava, it is admitted that in only one case was physiologic proof obtained. However, in view of the fact that several proved cases have been presented in the literature and that all of these have had identical roentgenologic findings, and of the fact that no other condition is known to give this appearance, there is sufficient justification to add the physiologically unproved cases. This is done with the intent of drawing further attention to these cases, since they are probably less rare than previously thought. The cases presented have all been collected within the last two years.

The roentgenologic findings in cases of anomalous venous connection of the right lung to the inferior vena cava are sometimes less obvious than in cases of total anomalous pulmonary venous connection, but there are several features which may bring to mind the possibility: (1) The heart usually, but not always, projects into the right hemithorax more than it normally would. In some cases it is even totally rotated into the right side of the chest. (2) The right hemithorax may be slightly smaller than the left, and bronchograms in such cases may show hypogenesis or agenesis of a portion of the right lung. (3) The anomalous vein may be seen coursing as a saber-shaped shadow along the right paracardiac region. If tomograms are obtained, it will be seen to start as small tributaries, sometimes from as high as the apex; these gradually merge and eventually a large main trunk is seen which courses in the general direction of the right cardiophrenic angle. Even if the main vein cannot be seen on the routine posteroanterior film, its presence should be suspected if the pulmonary vascular markings along the right border of the heart appear unusual in that they seem to taper *toward* the hilus. Bucky films are usually not particularly effective in clarifying the picture, but tomograms may be dramatic.

Some of these cases are associated with an atrial septal defect. In one such case the atrial septal defect was corrected and the anomalous vein transplanted into the left atrium. This case is not presented here because the huge

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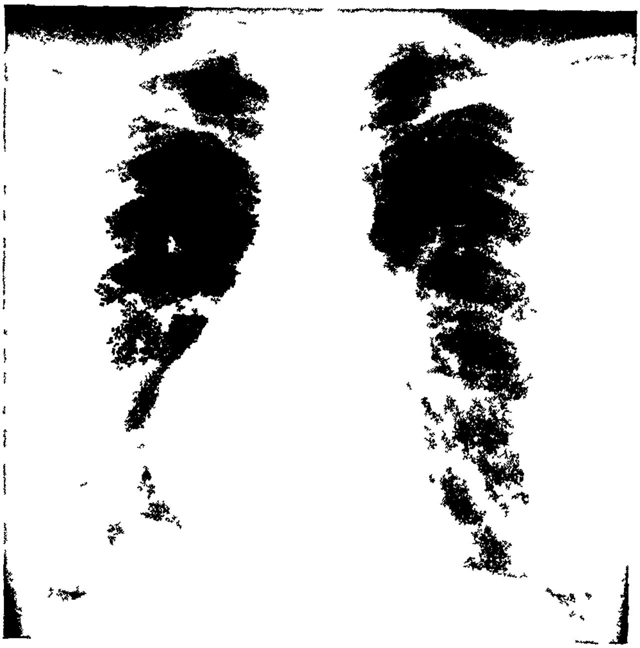

Fig 12—Case 10 Posteroanterior chest roentgenogram illustrates the large anomalous vessel in the right lower portion of the chest, which is undoubtedly an anomalous right pulmonary vein draining into the inferior vena cava As a result of this the right atrium is larger than normal and projects into the right side of the chest farther than it normally would

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Some of these cases are associated with an atrial septal defect. In one such case the atrial septal defect was corrected and the anomalous vein transplanted into the left atrium. This case is not presented here because the huge size of the heart prior to operation obscured the area of the anomalous vein entirely. After correction the heart size decreased by almost one half. Other cases—and probably the majority—are unassociated with an interatrial communication. This statement is based on the cases presented in the literature, as well as on the fact that in most of our cases there were no evidence of recirculation in the lung fields and no obvious cardiac disability. One such case with physiologic proof is presented. In another case, however, the clinical picture did suggest the presence of an atrial septal defect.

These cases are of interest in that they are within the realm of surgical correctability. It would be difficult to urge such a patient to undergo operation, because the condition is usually subjectively symptomless. However, to put the physiologic problem crudely, if such a patient were at any time to have pneumonia of the left lung, or for some reason underwent left pneumonectomy, death would be inevitable, since the right lung would not be able to contribute sufficient oxygenated blood to the systemic circulation even if an atrial septal defect were present.

SUMMARY

Cases are presented of the two types of anomalous pulmonary venous connection which are readily recognizable on the routine posteroanterior chest roentgenogram. These are (1) the "figure-of-eight" type of total anomalous pulmonary venous connection, and (2) anomalous venous connection of the right lung to the inferior vena cava.

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USE OF A NEW TOPICAL ANESTHETIC AGENT (DYCLONE) IN PERORAL ENDOSCOPY

A REPORT OF 569 PROCEDURES

FELIX A HUGHES, M D , JAMES R BURWELL, M D , AND JAMES W PATE, M D
MEMPHIS, TENN

A TOPICAL anesthetic agent which is potent, fast, nonirritating and non sensitizing is highly desirable for peroral endoscopy No known agent which is ideal in all of these respects is available so that newer drugs are constantly being evaluated Dyclone* has been used in procedures in this institution, this work forms the basis for this report

Dyclone (4n butoxy beta-piperidino propiophenone hydrochloride) is a white crystalline powder with the additional advantages of bactericidal and fungicidal properties[1 2] The compound, with the generic name of dyclonine HCl, is soluble at a 2 per cent concentration in water which is slightly acidic and stable in this solution Animal studies have shown good topical anesthesia in the cornea for 50 to 60 minutes without irritation. There is said to be no demonstrable parasympatholytic action and no change in the response to acetylcholine or epinephrine of the cardiovascular or gastrointestinal systems[1 2] To date, the incidence of allergic reactions to the agent is about 0 05 per cent of all cases, the majority of which occurred in the topical application of Dyclone cream In thousands of cases in which Dyclone solution has been used in the eye, mouth, bronchi, and urethra, no sensitivity has been reported Using *Staphylococcus aureus* as the test organism, the absolute phenol coefficient is 3 6[3]

In these studies, using a standard technique with Jackson cross action forceps the soft palate, tonsils pillars pharynx, and pyriform sinuses were swabbed with cotton which had been saturated in either 0 5 or 1 per cent solution Approximately 7 c c was used for this stage Under indirect laryngoscopy, about 10 c c of 0 5 per cent solution in 1 to 2 c c aliquots was injected into the larynx and trachea for bronchoscopies and bronchograms For esophagoscopies and esophageal dilatations, the patient swallowed a similar amount of the 0 5 per cent solution The time required for good anesthesia was about 6 minutes The anesthesia generally lasted from 30 to 45 minutes which was adequate time for performance of the desired examination yet brief enough to allow recovery from the anesthesia before leaving the clinic

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From the Thoracic Surgery Section Veterans Administration Medical Teaching Group Hospital Memphis 15 Tenn
Received for publication Dec 19 1955

*(dyclonine HCl)—Pitman Moore Company Indianapolis 6 Ind

A total of 400 patients was anesthetized in the above-described manner and 569 procedures were performed. The types of procedures are listed in Table I. No procedure was abandoned because of inadequate anesthesia. No untoward reactions were encountered with the exception of one instance, a 27-year-old, white, frightened nurse who complained of vertigo, sharp lancinating pain in both ears, paresthesia (tingling) of the hands, and acute dyspnea. There was no change in blood pressure, and pupil reaction and tendon reflexes were normal during this episode which lasted for approximately fifteen minutes and subsided spontaneously with no treatment. A similar reaction occurred on the ward when this patient had no anesthesia. This would indicate that this episode was a manifestation of hysteria.

Table I

Bronchograms	182
Bronchoscopies	313
Esophagoscopies	39
Esophageal dilatations	35
Total procedures	569

Recently, we have used Dyclone to alleviate the pain of esophagitis in 15 patients receiving deep x-ray treatment for nonresectable carcinoma of the lung. Fifteen minutes ante cibum, 5 c.c. of Dyclone 1 per cent is placed in the oral pharynx and the patient swallows the drug. We have found that the pain of swallowing food is alleviated partially or entirely with this regimen but the patients complain of inability to taste the food and numbness of the tongue.

One patient has been anesthetized thirty-five times for esophageal dilatation at intervals of one week. To date, no evidence of any toxic effect has been determined. Liver and renal function tests are normal; peripheral and bone marrow blood studies are normal.

SUMMARY

A total of 400 patients were locally anesthetized with 1 per cent and 0.5 per cent Dyclone with prompt, adequate anesthesia for peroral endoscopy.

No untoward reactions or toxic effects were noted in this series.

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Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-seventh Annual Meeting of The American Association for Thoracic Surgery will be held May 4, 6, and 7, 1957, in Chicago, Illinois. Headquarters will be at the Palmer House.

Requests for Hotel Reservations

These should be mailed directly to Mr. Edward Langford, Reservations Manager, Palmer House, Chicago. Please mention this Association, the type of accommodation desired, the date, and approximate hour of arrival and departure. If accommodations are desired elsewhere in Chicago, please communicate directly with the hotel of your choice.

Thoracic Surgery Forum

The Thoracic Surgery Forum will be continued as a special session at the 1957 meeting. The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies, and modified or new surgical techniques. The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferal to the Regular Program.

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper.

All Thoracic Surgery Forum papers will be published together in one issue of the JOURNAL. Maximum length: 3000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts of Papers

Abstracts of all papers for presentation at the 1957 meeting must be received on or before Dec. 15, 1956, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Thoracic Surgery Forum" or "For Regular Program." The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Five, repeat, five copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 600 South Kingshighway, St. Louis 10, Missouri.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves*, together with descriptive material concerning length of presentation, etc., must be received by Dr. Karl P. Klassen, The Ohio State University, Columbus 10, Ohio, before Dec. 15, 1956.

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions. If the films are well labeled, it will not be necessary for the author to be present for comment.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec. 15, 1956, otherwise the application will be deferred for consideration until the 1958 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. O. T. Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn.

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year. The new letters of recommendation should also be sent to Dr. Clagett, the Chairman of the Membership Committee.

Erratum

Through an error the name of Dr. Joseph L. Mangiardi of 426 Pennsylvania Avenue, Freeport, New York, was omitted from the list of Associate Members published in the June issue of this JOURNAL. It will be added to reprints of the official list of members.

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SOME OF THE FORGOTTEN MEN IN THE FIELD OF THORACIC SURGERY

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As an introduction to the talk I want to give this afternoon, I shall read to you from the Constitution of this Association. Article II deals with the object of the Association. It says: "The object of this Association shall be to encourage and stimulate investigation and study that will increase the knowledge of intrathoracic physiology, pathology and therapy, to correlate such knowledge and disseminate it." So, you see, this Association was not established to honor men who had already made contributions to thoracic surgery, but to encourage work in this field. Therefore, we should be interested in those men who have made noteworthy contributions, even if their work has not brought them fame. In speaking of them, however, I am not unmindful of the many men in this audience today who have made great contributions, and have also received just praise for it. I thoroughly agree with this acclamation and am sure that there is no one here who admires them more than I. To list them is unnecessary, for you all know them. I have no desire to detract in any way from this acclaim. I only want to add to this group the names of some others who, I think, should be among them.

The first subject I want to talk about is one that is familiar to everyone. I refer to decortication of the lung. This procedure was first publicly described by G. R. Fowler,[15] in 1893. There is some evidence that Carl Beck[5] did this operation at an earlier time, but he did not publish a report of his work which had been presented before the German Surgical Society in New York. During the two years following Fowler's paper, Délorme[11] in France, and Lambotte[19] in Belgium, wrote about this procedure and reported their experience with it. Their operations differed from the modern one only in

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regard to resection of the chest wall and in the method of drainage. They resected large segments of many ribs and packed the wound open with gauze after completing the decortication. Although the operation was widely discussed, it was not widely used, and one can well understand why that was true, as blood transfusion was far in the future. Between that time and 1918, the procedure was only occasionally discussed in the literature.

In the latter part of 1918, when the First World War was drawing to a close, there was the terrible influenza epidemic and a tremendous number of cases of empyema developed among the survivors. A great many of these occurred in the soldiers, and at Walter Reed Hospital in Washington, Col. William Keller and Dr. Carl Eggers, had charge of them. They published many articles on the subject, and Dr. Eggers[14] published the results of his use of decortication for chronic empyema. He performed the operation on 99 soldiers and only one of them died—no antibiotics, and no blood transfusions. Sixty-seven of the men had excellent results with re-expansion of their lungs. The others needed further plastic operations. The operation which he did then, as published in the *Annals of Surgery* for March, 1923, was very similar to that done today and I am going to show you some lantern slides to illustrate the various steps. The only point of difference had to do with drainage. He used an open tube, although Dr. Mann,[24] Professor of Surgery at the University of Minnesota, as far back as 1907 emphasized the importance of closed drainage in such circumstances. After this important report, Dr. Eggers did not publish any further ones, presumably, because he felt that nothing further needed to be said. In spite of his excellent results, the operation was not accepted. Hedblom[34] reported on his experiences at the Mayo Clinic with 150 cases of chronic empyema treated between 1917 and 1920 in which he did decortication in 30. In 15, the results were excellent. He felt that the operation had a place, but a limited one. Practically all of the other leading thoracic surgeons in this country were opposed to this procedure. They felt it was too formidable an operation for rather limited results. Dr. Bigger was the only other man I knew, besides myself, who felt the operation should be used. I tried it successfully, in 1929, for a chronic empyema and again, in 1940, for a chronic hemothorax. In the autumn of 1943, I gave a talk on the subject before the county medical society in Memphis and reported on 3 cases which had been treated at Kennedy General Hospital. As I had nothing new to offer I never published anything on the subject. Soon after this, in North Africa and Italy, decortication was found to be very effective in treating chronic hemothorax in the wounded soldiers, and the reports of Samson, Burford, Brewer and Burbank, and others, brought the procedure to the eyes of all. Soon it was found that decortication was just as useful in cases of empyema, and since then it has been applied to all types of cases in which the lung has been entrapped by a membrane. In none of the numerous papers written on the subject since 1943 have I seen a single reference to the work of Dr. Eggers. Surely his name should stand together with those of Fowler[15] and Délorme.[11]

Now, I want to move over into a very different field of activity. The surgery of mitral stenosis has changed from a spectacular operation, in 1948, to a procedure that is successfully used throughout the entire world. The recently trained thoracic surgeon today, looks upon mitral commissurotomy as we older men looked upon appendectomy. And yet, the development of this operation took a great many years, and passed through stages when the leaders in the field thought that further work on the subject was futile with the means then at hand. However, with no new weapons, the operation became established. Back in 1898, an English physician by the name of Samways[30] said in an article on the peristaltic movements of the auricle that notching the stenotic mitral valve might be of value in treating mitral stenosis. That is all he said, and did not write further about this idea. However, in 1902, Sir Lauder Brunton[7] published an article in the *Lancet*, on February 8, in which he very decidedly advocated the resection of a segment of the stenotic mitral valve. Let me read you what he said: "Mitral stenosis is not only one of the most distressing forms of cardiac disease, but in its severe form it resists all treatment by medicine. On looking at the contracted mitral orifice in a severe case of this disease, one is impressed by the hopelessness of ever finding a remedy which will enable the auricle to drive the blood in sufficient stream through the small orifice, and the wish unconsciously arises that one could divide the constriction as easily during life as one can after death. . . . But no one would be justified in attempting such a dangerous operation as dividing a mitral stenosis in a fellow creature without having first tested its practicability and perfected its technique by previous trials on animals." He then went on to say, that he had obtained the necessary licenses to do the work, but because of pressure of other duties had only been able to do the operation on cats, dead animals, and diseased hearts obtained at post-mortem. Then he said, "It may be some months longer before I can get anything more done and I therefore think that it may be worthwhile to write this preliminary note, especially as after all, if the operation is to be done in man, it will be surgeons who will do it and they must, of course, make their own preliminary experiments, however fully the operation may be described by others, and each must find out for himself the method which he will employ in each particular case." In spite of the caution expressed in this article, and the statement that surgeons would have to work out the technique, he was severely attacked in the *Lancet* by a leading article the week after his article appeared. He was attacked for suggesting such a radical procedure without first having perfected the operation himself. And yet, everyone knew that he was not a surgeon but was one of the most distinguished cardiologists in England, and even a Fellow of the Royal Society. The only surgeon who entered into the discussion was Sir Arbuthnot Lane,[22] who said that he considered the operation feasible, and "under certain circumstances justifiable." He said nothing else, and no other surgeon had anything to say. This reticence on the part of the surgeons is of great interest when one looks back at the state of surgery at that time. In looking through the *Lancet*, the *British Medical Journal*, and *Annals of Surgery* for that year I was tremendously interested in reading of the great amount of surgery being done at that time. Abdominal surgery was well advanced and had Sir Lauder proposed some new abdominal procedure it would have been carried out at once. It might be of interest to cite here a few of the surgical events chronicled in these journals. But first it might be well to point out that England was then engaged in the Boer War which did not come to an end until June 1, 1902. Marmaduke Sheild,[31] of London, reported the results of operation in 60 cases of malignant tumors of the breast. He pointed out the importance of the radical operation, and said that Halsted was to be congratulated because he had revived the operation introduced by Moore of the Middlesex Hospital in London, in 1867. He concluded his article by saying, "operate early, operate extensively." There was a paper on hysterectomy for cancer of the uterus with the statement that the vaginal route was the better one in most cases. A. W. Mayo Robson[26] reported on 200 operations for obstructive jaundice with a mortality of 13.6 per cent. Most deaths were due to hemorrhage. This was five years before Crile started doing transfusions, and eight years before typing of blood really became established, and transfusions could be safely used. One of Europe's greatest surgeons, Doyen[12] of France, reported on the isolation of a diplococcus which he considered to be the etiologic agent in cancer. He said that he had been able to isolate it in every one of his cancer cases. He had prepared a vaccine and had used it in all patients except those with the rapidly growing tumors. In the same year, April, 1902, at the German Surgical Congress[13] he had shown moving pictures of trephining, resection of the knee joint, and finally his famous operation for separation of the xiphopagus Hindu girls. There was a report in the *Lancet* in that year of the meeting of the Society of Anesthetists of Great Britain, on Dec. 6, 1901. At this meeting the chief subject for discussion was "Is Chloroform More Dangerous than Ether? Consideration of Respiratory Troubles Following Operations During Twelve Months at a Large General Hospital." In spite of the fact that there were a large number of doctor anesthetists in England at that time, and much interest was taken in it, there was no satisfactory anesthesia for chest surgery. Although intratracheal anesthesia had been introduced by Matas,[25] in 1901, it had not been used to any extent except in experimental work, and without it it was impossible to operate in the open chest. Only by first creating adhesions in the chest was it safe to open the chest for an operation as the uninvolved part of the lung had to adhere to the chest wall so as not to collapse when the chest was opened. Rehn, in 1896, had successfully sutured a stab wound of the heart and others had been done since then. The management of stab wounds of the chest had been well worked out, and the dangers of pneumothorax were understood. However, no surgeon of that day would lightly consider operating in the open chest and no one would dare operate on the heart except to suture a wound in it. Shortly before Rehn's successful case, the great

Billroth had declared that any surgeon who dared operate on the heart would lose the respect of his fellow surgeons. So, it is not surprising that no surgeon ventured to follow Sir Lauder Brunton's suggestion.

Although no surgeons in England became interested in the possibility of surgery for heart disease, a great deal of experimental work was done in Germany, France, and in this country after this In 1922, Graham and Allen[2] began work on surgery for mitral stenosis, and in dogs, succeeded in biting out pieces of the mitral valve with an instrument with which they could see the tissue which they cut. Allen[3] succeeded in getting an answer to the question as to what happened to the valve after it was cut. Many thought that a valve that was divided, or cut, would heal and restore the stenosis. Allen told me recently, that he talked the matter over with Dr. Caulk, the noted urologist in St. Louis. Allen compared the stenotic mitral valve to a urethral stricture. The great difference being that urine passed infrequently through the urethra, while blood poured continuously through the mitral valve. Believing that the valve would not resume its structure, he tried the problem experimentally. He cut the valves of a series of dogs, and eleven months later studied them. The cut edges had become epithelized, and there was no tendency to recurrence of the stenosis With this knowledge, and having perfected their technique on dogs, Graham and Allen searched in vain for a patient. They planned to approach the [illegible] by way of the auricular appendage. None of their colleagues at Washington University were interested. Finally, a doctor from out in the country sent them a patient. She was so sick that they planned to operate on her in stages. Even so, at the third stage she died, just as they were getting [illegible] to introduce the cardioscope. After Graham and Allen had done many of their experiments, Cutler and Beck,[10] in Boston, began work on the problem, and finally in April, 1923,[?] they succeeded in dividing the stenotic mitral valve of a young girl by the ventricular approach. She recovered, and her case was promptly reported. News of this great event spread throughout the world, and it was generally thought that a new era of thoracic surgery had dawned. It was the intention of Cutler and Beck to resect a segment of the mitral valve as they thought that was necessary to correct the stenosis. In their first case, however, they had decided that they had better be content with simple division of the valve. In their subsequent cases they did carry out resection, but all of the patients died. Two years after Cutler and Beck's successful case, Henry Souttar in London, operated on a young woman who was supposed to have mitral stenosis. He approached the valve as Graham and Allen had done, by way of the auricular appendage, and found on finger exploration that there was no real stenosis, but some regurgitation. He inserted his finger through the valve and explored both the ventricle and auricle, and wrote that [illegible] this was the proper attack on mitral stenosis His patient [illegible] lived for some years. At this time, in England, the teachings of Sir James Mackenzie were authoritative and everyone followed [illegible] He had died at 72, some six months before Souttar did [illegible] through the *Lancet,* the *British Medical Journal,* and *Annals of Surgery* for that year I was tremendously interested in reading of the great amount of surgery being done at that time. Abdominal surgery was well advanced and had Sir Lauder proposed some new abdominal procedure it would have been carried out at once. It might be of interest to cite here a few of the surgical events chronicled in these journals. But first it might be well to point out that England was then engaged in the Boer War which did not come to an end until June 1, 1902. Marmaduke Sheild,[31] of London, reported the results of operation in 60 cases of malignant tumors of the breast. 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In 1946, as you all know, Bailey[4] was operating on a patient with mitral stenosis, and was prepared to resect a segment of the valve with a cardiovalvulotome. After entering the auricular appendage, he discovered that he would be unable to get his instrument through the valve in order to do the resection. His medical associates told him that if he didn't relieve the stenosis in some way the patient would die on the table. Suddenly, he remembered Souttar's article, and pushed his finger through the valve, splitting the commissures. Although the patient died a day later, the autopsy revealed the fact that the stenosis had been corrected without the establishment of regurgitation. He knew then that Souttar's operation was the correct one, but he had to wait two more years before he had another chance to do the operation. Then, in June of 1948, he operated on a young woman and succeeded in carrying out the operation. Six days later in Boston, Dwight Harken[18] carried out a similar procedure, but cut along the commissures with a valvulotome. Three months later in London, Russell Brock[6] carried out the Souttar operation with success. None of these men knew of the other's work at the time. And so within the period of three months, an operation that had first been carried out twenty-three years earlier came into its own. To Brunton must go the credit for fighting for the principle of surgery for mitral stenosis. To Souttar goes the credit for perfecting the operation, and to Bailey, Harken and Brock go the credit for establishing the operation as a definitive procedure.

On May 6, 1907, at the meeting of the Philadelphia Academy of Surgery, Dr. John Munro[28] of Boston, read a paper entitled, "Ligation of the Ductus Arteriosus." So important were his remarks at that time that I shall quote from his address. He started by saying, "That I may be allowed to bring this suggestion for a new operation before your Society, I ask on the basis that it has not been hastily conceived. On the contrary long ago I demonstrated its technical possibility on the cadavers of newborn children, and felt that it was justifiable on the living. At various times I have tried to inspire the pediatric specialist with my views, but in vain. Now, in view of the recent advances in cardiac surgery, for much of which we are indebted to the surgeons of this city, I will venture to place my ideas before you, asking that you do not dismiss them hastily.'' He then went on to record the case of a girl baby that presented evidence of heart disease, and died after several weeks without any real cyanosis. At autopsy, the only abnormality found was ''an open ductus arteriosus lying easily within reach behind the sternum. The simplicity of the remedy was so striking that I at once made further dissections, and satisfied myself that it would be possible to ligate the duct provided a diagnosis could be made beforehand. In regard to making a diagnosis, however, my pediatric advisers were not reassuring.'' He then spoke of studies made on the ductus, and the effort to recognize distinctive heart sounds. As the ductus is normally open during the first few days of life, it was thought that it would be possible to establish the auscultatory signs that were typical, from examination of many newborns. This did not prove to be true, although Townsend examined 100 newborn babies during the first three days of life. He then discussed the question of the etiology of delay in closure of the ductus, and said that nothing was known about this.

His description of the characteristic findings in a case of patent ductus is still true in most respects. First, he said that there was no cyanosis, except occasionally in late life. ''Cardiac dullness is increased laterally, and there may be projection and pulsation of the dullness leftwards, in the upper costal spaces. This projection is visible by x-rays. A loud systolic whir conducted into the cervical vessels may be heard, but as a matter of fact there are no definite auscultatory signs established as yet. Of the 26 cases collected recently, half lived to puberty. Death follows from atelectasis, general oedema, pleural exudate, pneumonia, endocarditis, etc.''

''Why should we consider surgical interference in cases of open ductus arteriosus? Because in spite of the fact that some cases may live to puberty, the chances of which must be small, we have the one cardiac-valvular lesion, which is, relatively speaking, superficial. Furthermore, the anomalous vessel is of good size, its ligation must be followed by instant and permanent restoration to a normal function of the lungs and arteries, and it can be reached by a short surgical route.''

''The operation I would propose, as demonstrated on the cadaver, is as follows: Under ether anesthesia, which I prefer to chloroform in any case involving collapse of the lung, the sternum can be easily split along its center or a little to the right, opposite the second costal cartilage. This is easily done with a knife. The sternal halves are then retracted, ample room for working being obtained. The right pleural cavity will probably be opened but the left one will not. Judging from analogous cases in surgery, t should not be serious, but if necessary the physiologist's apparatus for m opinions about the heart were universally followed. Therefore, Souttar was unable to get any more patients on whom to operate, as Mackenzie had held that the important feature of mitral stenosis was the damaged myocardium, and that the valve deformity was of secondary importance. Thus, it was useless to operate on the valve. In this country, Dr. Samuel Levine,[23] in Boston, did not agree with Sir James, and he referred a number of patients to Cutler for operation, even though all died after the first one. The fact that Souttar's patient did not have true stenosis, and therefore was unaffected by the operation, accounted in some degree for the lack of attention attracted by his article. During the time that Cutler and Beck were operating on their patients with mitral stenosis, no one had been able to produce mitral stenosis in the experimental animal. However, between 1929 and 1932, John Powers,[29] working in the same laboratory at Harvard where Cutler and Beck had done their work, found that he could produce stenosis by cauterizing the mitral valve by means of bipolar diathermy, and then infecting the dogs with *Streptococcus viridans.* He then studied the effect of resecting portions of the valve, and found that, in every instance, the dog died from the regurgitation produced.

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"Would it be justifiable to subject a child to this risk without knowledge of the exact lesion? In a case with beginning atelectasis or other evidences of impending death from circulatory disturbances, with a reasonable basis for believing that the duct were open, it seems as though such an operation would be justifiable. I doubt if it would materially hasten a fatal issue in case the diagnosis were not confirmed."

Why was it then that this operation was not attempted? In spite of Munro's remarks about the control of pneumothorax by the physiologist's apparatus for maintaining artificial respiration, this was rarely used in the operating room, and apparently was not thought to be of practical value. At that time, surgeons were repairing stab wounds of the heart, draining lung abscess and empyema, and resecting chest-wall tumors, but they were not operating in the open chest. It was considered safe to operate on a lung, or in the chest, only if the lung were firmly adherent to the chest wall. So that it was not feasible to undertake an elective operation in the open chest. Furthermore, blood transfusion, although successfully done by Crile[8] in 7 cases, by artery vein anastomosis and unmatched blood, had not come into use. This was four years before Moss[27] demonstrated the four types of blood, and blood typing was done. It is true that Landsteiner[20, 21] had demonstrated types of blood in 1900 and 1901, but Crile even went so far as to say that he was convinced that it was perfectly all right to transfuse blood from any member of a species to any other member. Why he had no reactions in his 7 cases is not known. So, blood transfusion was not available at that time. Who today would undertake to ligate a patent ductus without having blood available for possible use?

Thirty years after John Munro had suggested ligation of the patent ductus it was finally attempted by John Strieder,[33] in Boston. Although Munro had described the operative approach to the problem he had been unable to convince any pediatrician that the operation was feasible, and so never had a chance to do the operation himself. Maude Abbott,[1] the great authority on congenital heart disease, in the last article she published (the article appeared in *Nelson's Loose Leaf Medicine* for 1942, but she had died in 1940) said that ligation of the ductus arteriosus had been suggested by Munro, but so far as she knew no one had attempted it. She felt that this was fortunate, as she believed that ligation of the ductus would invariably lead to production of an endarteritis, and the end condition would be worse than the original one. She did say, however, that if an obliterated ductus caused pressure on the trachea or esophagus it could safely be divided with benefit to the patient. Dr. Ashton Graybiel,[16] the cardiologist at the Massachusetts Memorial Hospital, felt that ligation of the ductus was a rational procedure, and discussed the subject with John Strieder, and with Dr. John Munro's son, Donald, a neurosurgeon. At that time it was not known whether or not Dr. Munro had attempted the operation. A search of his papers, and of the literature, failed to reveal any evidence of this. John Strieder[33] then carried out dissections in the pathology laboratory on cadavers, and so was ready to attempt the operation when Dr. Reginald Fitz referred to him a girl who was desperately ill with subacute bacterial endocarditis complicating a patent ductus arteriosus. It was thought that ligation of the ductus would save her life. The operation was done on March 6, 1937, but it was found that the pulmonary artery and the aorta were in contact, and although it was possible to separate them everywhere except posteriorly it was impossible to pass a ligature around the ductus. He then made an attempt to plicate the ductus, and a series of silk sutures were placed with almost complete disappearance of the thrill. She did well for three days and the murmur could no longer be heard, but on the fourth postoperative day, she developed an acute gastric dilatation and died in spite of everything done to correct the condition. At autopsy, it was seen that the vegetations extended from the orifice of the ductus downward to the pulmonary valves. This case report was given at the Saranac Lake meeting of the American Association for Thoracic Surgery on June 1, 1937,[33] during the period for discussion of the papers by Beck on "Augmentation of the Coronary Circulation by Operation," and by Blalock on "Tuberculous Pericarditis." He continued his discussion by saying, "We are reporting this in some detail later, but I thought I might take the opportunity to present it to the Society in case anyone had thought along similar lines and would be interested in trying it as a prophylacti measure in youngsters before they already have dilatation and hypertro[illegible] of the heart, and also because 25 per cent of these patients with cong[illegible] heart defects die of subacute bacterial endocarditis, or endarteritis." F[illegible] ing this presentation, no one at the meeting had any comment to make[illegible] following year in the *American Heart Journal*, Graybiel, Strieder, and [illegible] reported the case in more detail. In the conclusion to the article he said tha[illegible] in the future, in addition to ligating the ductus, he would attempt to obliterate the adjacent portion of the pulmonary artery so as to remove all the vegetations from direct contact with the blood stream, and in allowing the natural defense forces to kill the bacteria. He also said that the vegetations might be removed by a modified Trendelenburg operation.

In 1939, John Hubbard[17] was in charge of the Congenital Heart Clinic at the Children's Hospital in Boston. He was interested in someone's attempting to correct surgically some of these congenital defects. He got Robert Gross[17] interested in the subject and they decided that the ductus was the first to attack. They were familiar with Munro's article. Gross then worked in the surgical research laboratory at Harvard, with Cutler's backing, and then on cadavers, to perfect an approach to the ductus. He had not been present at the meeting of this Association in Saranac Lake when Strieder made his comments, had not seen his article which appeared the following year, and did not personally know him at the time. He was therefore unaware of the attempt made by Strieder to ligate the ductus. In August, 1938, he operated on a young child with an uncomplicated patent ductus and succeeded in ligating it. The child recovered and the fame of the operation spread throughout the world.

And so I have talked about some matters that are known to many of you, and have brought fresh light to bear on them. It is not that I want to destroy any reputations, rather do I wish to add to the illustrious list known to everyone, the names of some less well known but surely deserving of attention. I hope that I have succeeded in this attempt.

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OBSERVATIONS ON A CONSERVATIVE APPROACH TO NONMALIGNANT LESIONS AT THE CARDIA

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SO long as excision of the cardia is accepted as the best treatment yet available for carcinoma of this region, extirpation should be as complete as possible. The function of the cardia has already been destroyed by the growth. The aim of the surgeon, therefore, is first to eradicate the disease, and only second to repair the defect by a method which will give the least postoperative discomfort or complication. In the surgery of nonmalignant lesions, however, there must be a greater concern for the preservation or restoration of normal function.

While radical total gastrectomy for carcinoma and reconstruction by a Roux loop represents one extreme, at the other there is the reduction and fixation of a diaphragmatic hernia which restores the cardia to its natural state. Between these two, there are fields which have become much more interesting to explore.

Cardiospasm suffered too long from an overardent surgical approach before the simple myotomy of Heller became widely accepted, but this operation is now one of the most effective conservative measures at the cardia, and, for cardiospasm is used to the exclusion of all other open operations. Endoscopic dilatation by one of the many types of inflatable balloon may be considered equally conservative and yet simpler to perform but, although this still has an important place in the treatment of uncomplicated cardiospasm, it can have certain disadvantages: it is not always effective for as long a time as myotomy; it is less certain in its immediate result; and it may so stretch the hiatus and the fascial connections of the cardia that incompetence may occur. If it is performed successfully for a patient in whom cardiospasm is associated with hiatal hernia, incompetence is inevitable, and the same is true if cardiospasm is complicated by prolapse of the cardia into the abdomen. Reflux of digestive juices into the dilated and inert esophagus of cardiospasm, however it is produced, causes severe ulceration, bleeding, and perhaps stenosis, for any of which complications resection may be necessary. Laxity at the hiatus, prolapse of the cardia into the abdomen, or a true hernia can be detected and repaired during the open operation, and so the severe complication of peptic esophagitis may be avoided. These points are illustrated by the following case histories.

CASE 1.—L. H., a man aged 59, complained that for one year food had lodged behind the lower end of the sternum. It often returned mixed with large quantities of mucus. There had been no loss of weight. The radiograph showed an elongated, dilated esophagus with a smooth tapering obstruction at the cardia (Fig. 1). At esophagoscopy, the mucous

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Honored Guest's Address: Presented at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7, 8 and 9, 1956.

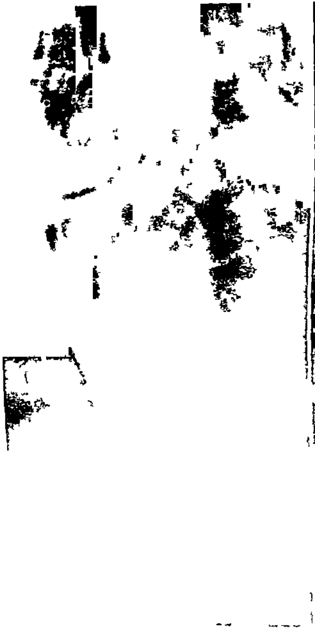

Fig 1

Fig 2

Fig 3

Fig 1.—Case 1 Radiograph of esophagus before treatment suggesting uncomplicated cardiospasm

Fig 2.—Case 1, Eight months after Negus dilatation Reduction in size of the esophagus is evident but there is rigidity and deformity of the lower end suggesting fibrosis

Fig 3.—Case 1. Four years after resection of stricture and esophagojejunostomy by Roux loop

membrane was redundant but clean, and the cardia soft. The instrument was passed into the stomach without difficulty, and the cardia was dilated with the Negus hydrostatic bag. After this, the dysphagia was temporarily relieved but the patient complained of heartburn and belching. Eight months later, when dysphagia returned, radiography showed the esophagus reduced in size but with a rigid area at the lower end suggesting a fibrous stricture (Fig. 2). The presence of ulceration and stenosis was confirmed by esophagoscopy. The ulcerated section was resected and esophagojejunostomy performed (Fig. 3), when it was noted that the cardia was 5 cm. above the hiatus. Histology of the specimen showed a benign ulcer. Fibrinopurulent exudate covered a floor of granulation tissue which was infiltrated by polymorphonuclear and eosinophil leukocytes and several large foci of lymphocytes. Beneath this was a zone of more cicatrized fibrous tissue, 3 mm. deep, and scar tissue extending into both muscle coats. He regained his lost weight and has been active and without symptoms, on a normal diet and intermittent liver therapy, for five years.

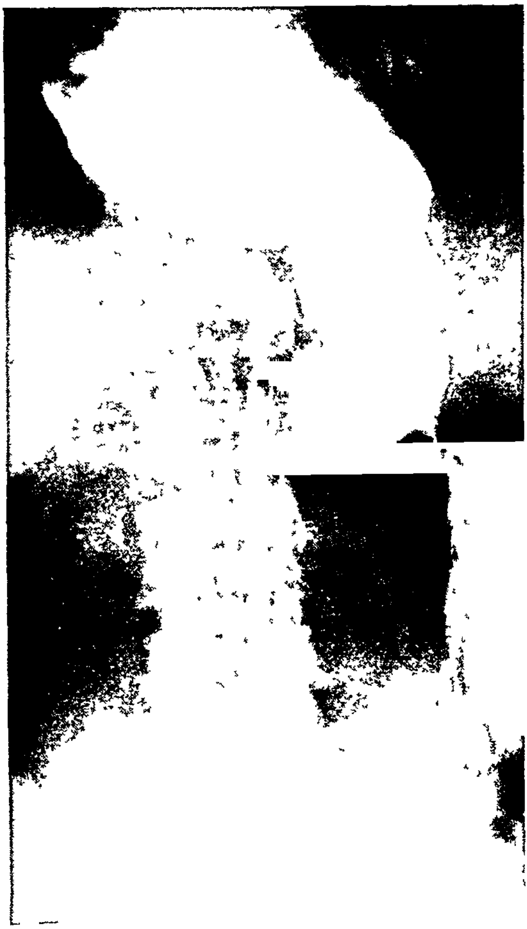

Fig. 4.

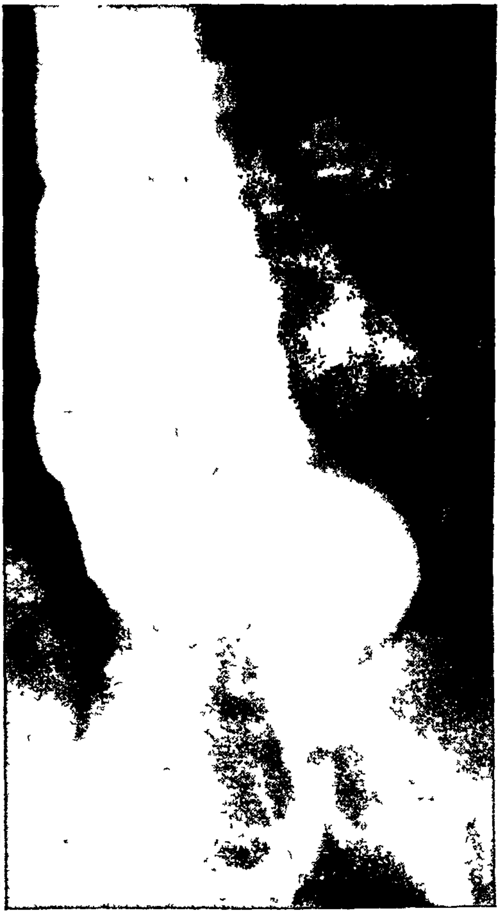

Fig 5

Fig. 4.—Case 2. Radiograph which shows cardiospasm with prolapse of the cardia into the abdomen for 7 cm

Fig. 5—Case 2 Two months after myotomy and restoration of normal relations between cardia and diaphragm. The cardia was competent

Case 2.—L. B., a woman aged 44, complained of dysphagia for seventeen years with regurgitation of food and mucus. The radiograph showed severe cardiospasm with prolapse of the cardia into the abdomen (Fig. 4). The condition was confirmed at operation, the dome of the diaphragm being incised to allow inspection of the cardia before any traction was applied. Seven centimeters of greatly hypertrophied esophagus lay in the abdomen. Myotomy was performed at the cardia, and the esophagus was then drawn up into the mediastinum. The fascia was sutured and the hiatus reduced to its normal size as in the treatment of hernia (Fig. 5). Relief was complete and no esophagitis occurred. After observation for four years without symptoms, the patient was discharged.

Case 3.—E. G., a woman aged 56, complained of regurgitation and vomiting for forty-nine years, and more severe dysphagia for two years. The dysphagia was always worse when she was excited. Radiography showed a dilated esophagus with a smooth obstruction at the cardia which was typical of cardiospasm (Fig. 6). When enough barium had passed the cardia to fill the stomach, the presence of a diaphragmatic hernia became manifest (Fig. 7). No esophagitis was detected at esophagoscopy, and the cardia was soft to the passage of bougies. The patient was operated upon by Mr. G. H. Wooler who confirmed the anatomic abnormality, performed a myotomy at the cardia, and repaired the hernia.

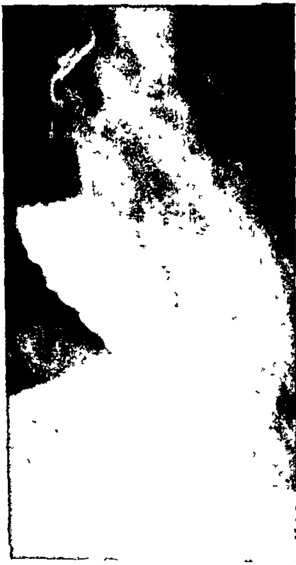

Fig. 6

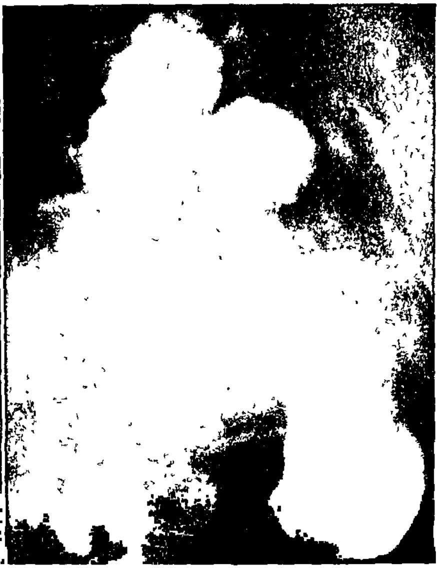

Fig. 7.

Fig. 6.—Case 3. Radiograph of an apparently uncomplicated cardiospasm.

Fig 7.—Case 3. A radiograph shows the esophagus nearly empty. Stomach filled. Abdominal compression demonstrates hiatal hernia complicating cardiospasm.

Sometimes the function of the cardia may be destroyed by faulty surgery and the question of its restitution arises. The situation is not necessarily hopeless and may be retrieved so long as deep fibrous scarring has not replaced the muscle elements, as the following example demonstrates.

Case 4.—D. H., a woman aged 39 years, had suffered for many years from pulmonary tuberculosis for which she had had a right-sided artificial pneumothorax and thoracoplasty.

For ten years she complained of retrosternal discomfort which was exaggerated by domestic anxieties. A radiographic examination showed a very active esophagus which, perhaps mistakenly, was diagnosed and treated as cardiospasm. The surgeon who performed the operation thought to increase the effectiveness of esophageal myotomy by incising the crural fibers on the left lateral side of the hiatus. After this, discomfort was greatly increased, the cardia incompetent (Fig. 8), and the esophagus was found to be extensively inflamed and superficially ulcerated. As no fibrous stenosis had developed, an operation was done to restore the competence of the cardia. The muscle fibers of the crus were found to be widely retracted where they had been cut, and the gap was filled with omental fat. The hiatus was very wide. The muscle of the esophagus also had retracted where the Heller myotomy had been performed and two Cushing clips had been applied to its cut edges. The mucous membrane was covered by a thin layer of fibrous tissue only. This tissue was excised, and the muscular coat of the esophagus was carefully freed and then approximated by fine interrupted catgut sutures. The scar tissue in the diaphragm was excised and the crural fibers sutured. The hiatus was then further reduced in size by one stitch in front of the esophagus and three behind. The dome of the diaphragm was incised and the ligaments of the cardia sutured to its under aspect by six interrupted silk sutures, as for a simple hernia. After this the esophagitis cleared up, and radiography confirmed that the cardia was competent (Fig. 9).

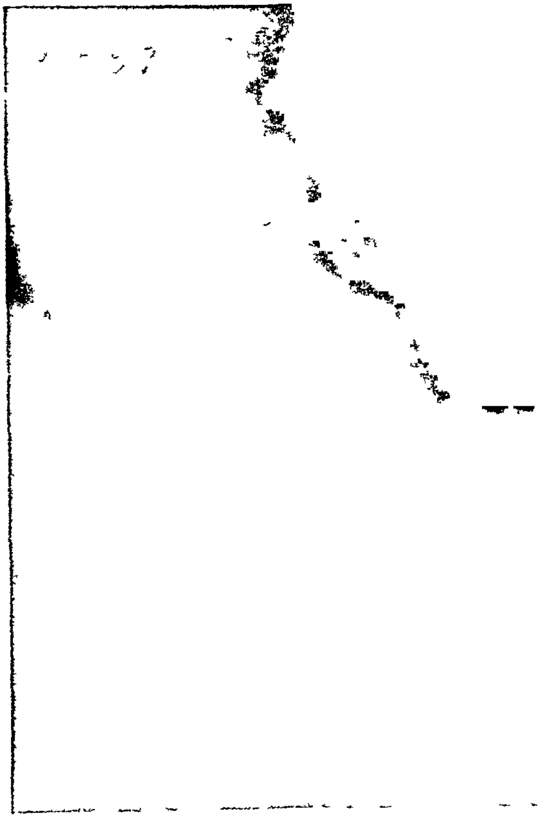

Fig. 8.

Fig. 9.

Fig. 8.—Case 4. A radiograph showing a patulous cardia after Heller myotomy and division of the crus on the left side of the hiatus. Cushing clips on cut edges of esophageal muscle.

Fig. 9.—Case 4. Restoration of normally functioning cardia by suture of muscle and fascial elements. The Cushing clips are 1.5 cm. above the cardia. The narrowing 4 cm. above this is apparent only, and caused by marked traction to the right of the mediastinum from pulmonary tuberculosis.

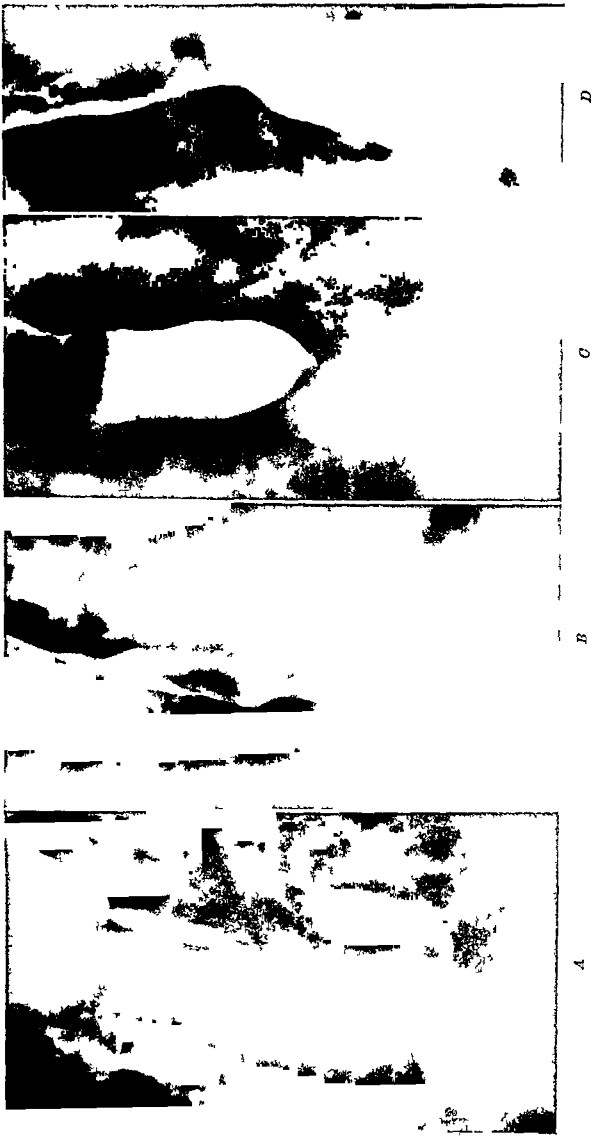

Fig 10—1 Long B medium C short and D weblike stenoses of esophagus from esophagitis secondary to hiatal hernia

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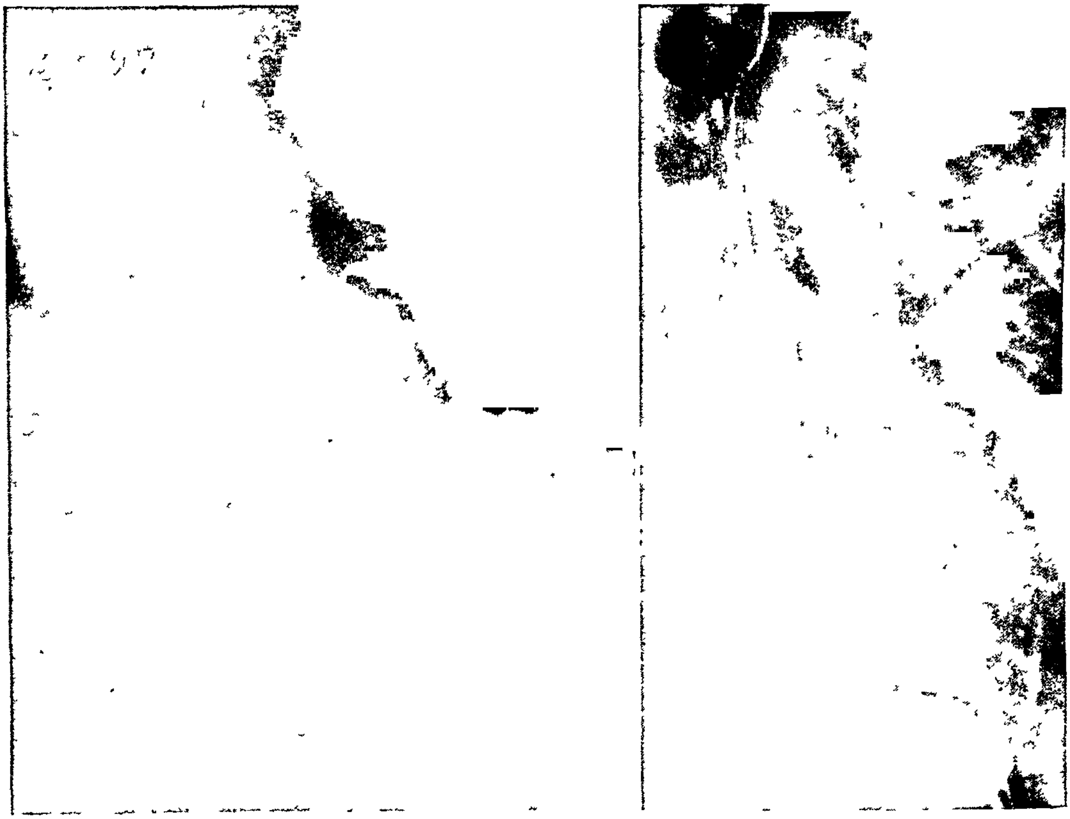

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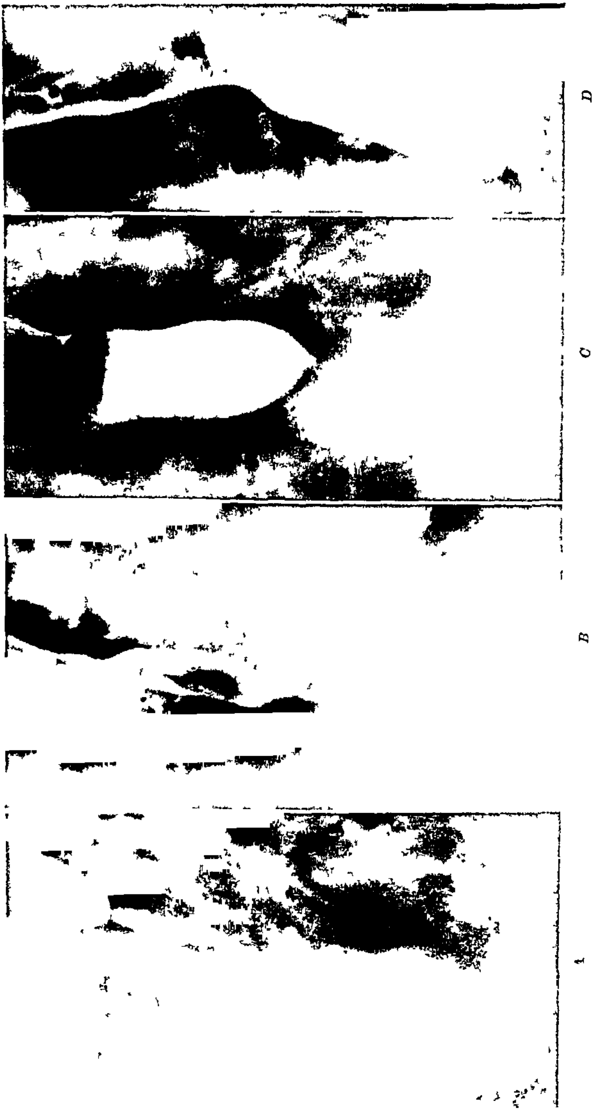

Fig 10 —*A*, Long *B*, medium, *C*, short, and *D*, weblike stenoses of esophagus from esophagitis secondary to hiatal hernia

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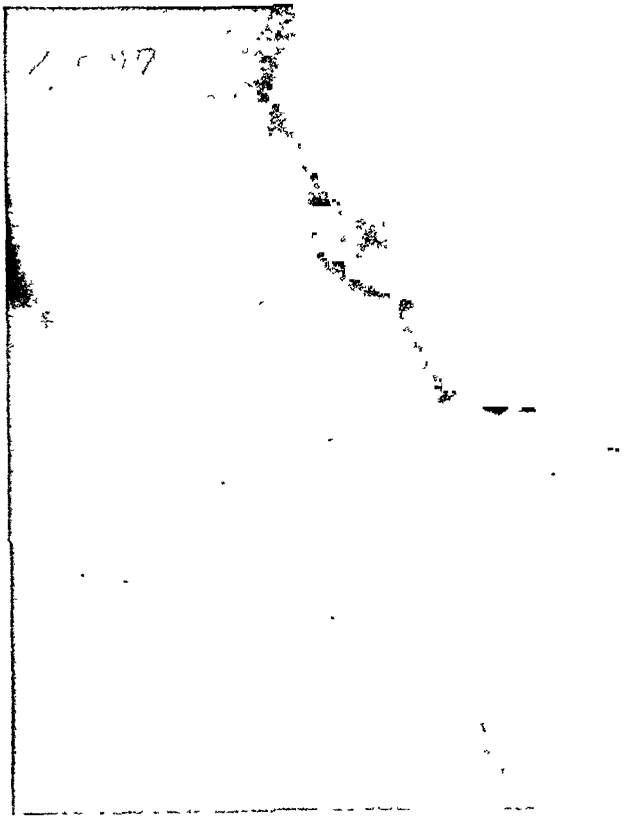
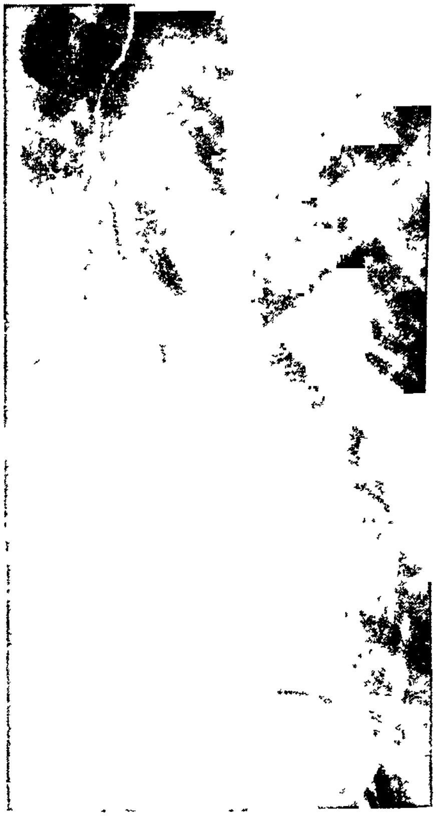


Fig. 8.



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CASE 5—P T, a man aged 46, complained for eighteen months of dysphagia, belching, regurgitation of food, and "gurglings" high in the epigastrium He had also lost weight and energy Radiography showed the crater of a simple gastric ulcer on the lesser curvature of the stomach, at the cardia (Fig 12) This ulcer could not be seen through the esophagoscope but the cardia was so distorted that a bougie could not be passed into the stomach The lesion was exposed through a left thoracoabdominal incision The esophagus looked and felt normal, but there was an induration of the stomach around the cardia The stomach was rotated forward, the lesser sac opened, and an incision made in the posterior wall of the stomach so that the ulcer could be inspected and palpated from within A tight fibrous stricture was felt to encircle the cardia completely, and this was associated with ulceration on its gastric side The cardia was isolated and cleaned on the outside, and then resected The resulting hole in the stomach was reduced in size by a few interrupted catgut stitches and then the anastomosis was made, the mucous membrane and muscle layers being joined separately by interrupted catgut As the exploratory hole in the back of the stomach was still open, the finger was inserted here and the anastomosis felt to be quite smooth on the inside The stomach was cleaned by suction and the hole in its posterior wall closed The fascia of the esophagus was stitched to the under aspect of the diaphragm as in the

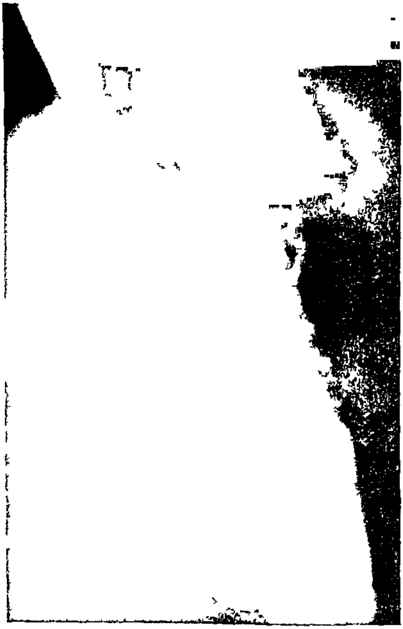

Fig 12

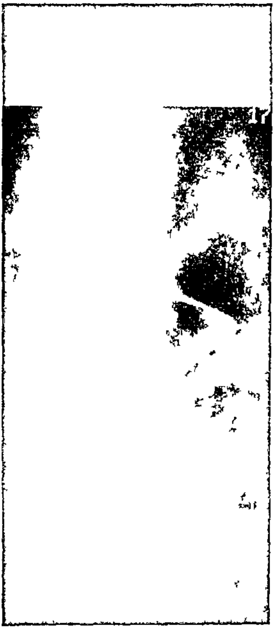

Fig 13

Fig 12 —Case 5 Radiograph which shows simple gastric ulcer crater on the lesser curvature just below the entrance of the esophagus into the stomach

Fig 13 —Case 5 One year after resection of the cardia and reanastomosis The depression seen just below the entrance of the esophagus into the stomach is caused by kinking and is not an ulcer crater

Some of the greatest difficulties arise in the treatment of the simple stenoses arising from peptic ulcers, and the problems vary according to the exact site and the morbid anatomy of the ulcers. The common esophageal ulcers in squamous epithelium associated with hiatal hernia may be very long, medium, short, or even weblike (Fig. 10), but more rarely an esophagus of normal length may be obstucted at its lower end by the fibrous reaction around a gastric ulcer very high up on the lesser curvature (Fig. 11). These all present different surgical problems and are therefore considered separately.

Fig 11 —*A*, Simple gastric ulcer high on the lesser curvature adjacent to the cardia. *B*, Three years later Partial healing with fibrosis obstructing the esophagus.

Esophageal Stenosis From High Gastric Ulcer.—A benign gastric ulcer in a normally placed stomach, adjacent to the cardia, and causing esophageal obstruction has been encountered by the author six times It may be difficult to be certain that the ulcer is not malignant. For this reason and because the possibility of reconstructing the cardia was not appreciated, it used to be resected, and continuity was restored by esophagojejunostomy. More recently, an effort has been made to resect the stenosis locally and to anastomose the esophagus to the stomach afresh, retaining the angle of entry, and suturing the fascia in such a way that the crus of the diaphragm encircles the lowest part of the esophagus and lies snugly in the angle between it and the fundus of the stomach. This may be illustrated by the following case report.

CASE 5—P T, a man aged 46, complained for eighteen months of dysphagia, belching, regurgitation of food, and "gurglings" high in the epigastrium He had also lost weight and energy Radiography showed the crater of a simple gastric ulcer on the lesser curvature of the stomach, at the cardia (Fig 12) This ulcer could not be seen through the esophagoscope but the cardia was so distorted that a bougie could not be passed into the stomach The lesion was exposed through a left thoracoabdominal incision The esophagus looked and felt normal, but there was an induration of the stomach around the cardia The stomach was rotated forward, the lesser sac opened, and an incision made in the posterior wall of the stomach so that the ulcer could be inspected and palpated from within A tight

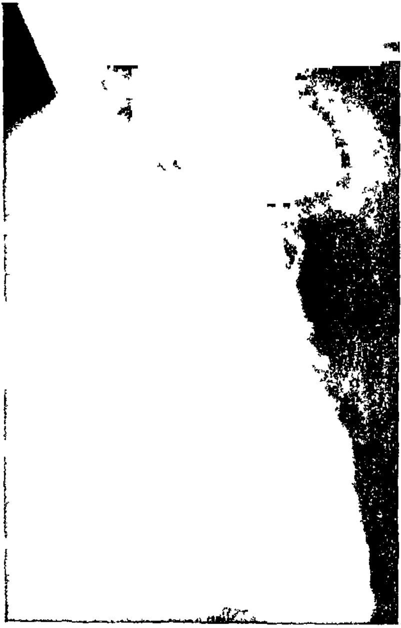

Fig 12

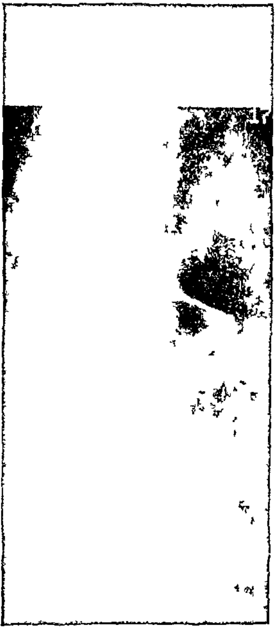

Fig 13

Fig 12—Case 5 Radiograph which shows simple gastric ulcer crater on the lesser curvature just below the entrance of the esophagus into the stomach

Fig 13—Case 5 One year after resection of the cardia and reanastomosis The depression seen just below the entrance of the esophagus into the stomach is caused by kinking and is not an ulcer crater

fibrous stricture was felt to encircle the cardia completely, and this was associated with ulceration on its gastric side The cardia was isolated and cleaned on the outside, and then resected The resulting hole in the stomach was reduced in size by a few interrupted catgut stitches and then the anastomosis was made, the mucous membrane and muscle layers being joined separately by interrupted catgut As the exploratory hole in the back of
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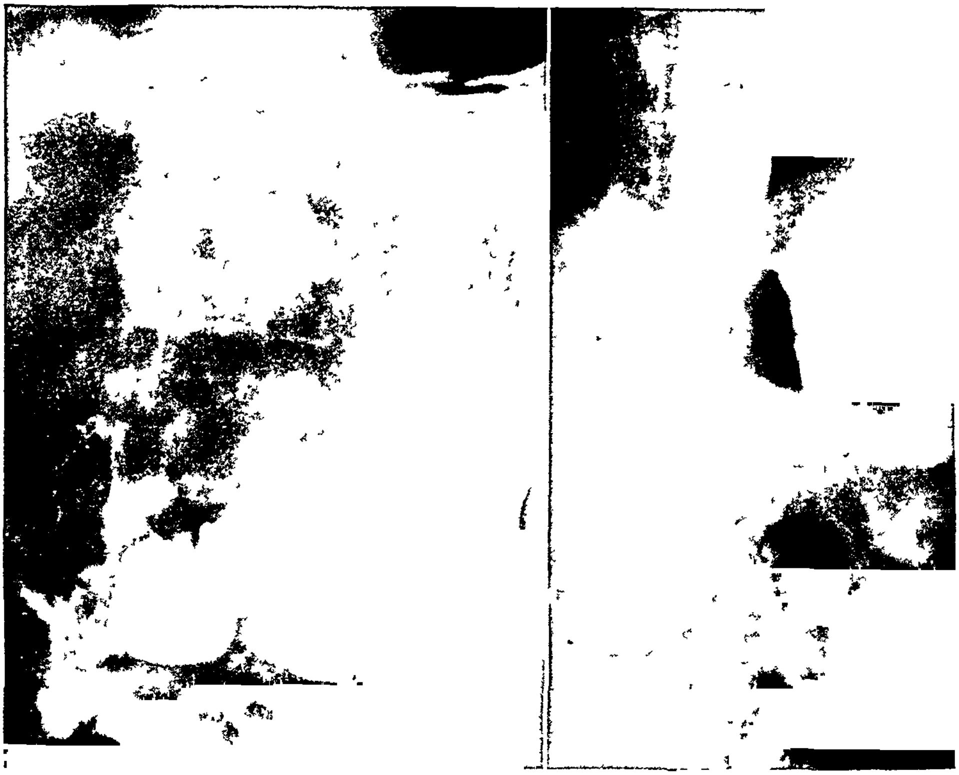
Some of the greatest difficulties arise in the treatment of the simple stenoses arising from peptic ulcers, and the problems vary according to the exact site and the morbid anatomy of the ulcers. The common esophageal ulcers in squamous epithelium associated with hiatal hernia may be very long, medium, short, or even weblike (Fig. 10), but more rarely an esophagus of normal length may be obstucted at its lower end by the fibrous reaction around a gastric ulcer very high up on the lesser curvature (Fig. 11). These all present different surgical problems and are therefore considered separately.



A. B.

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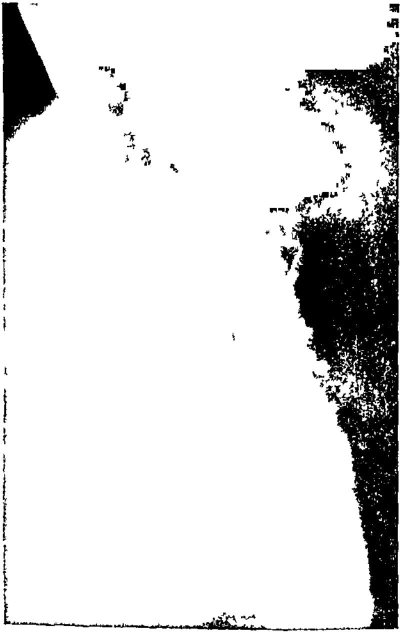
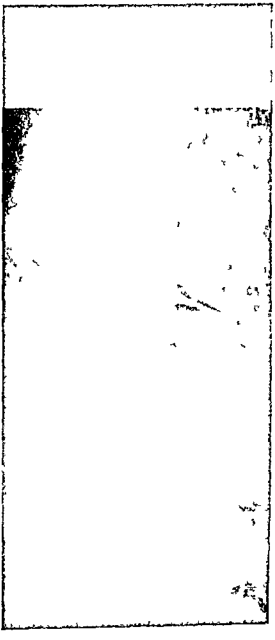


Fig 12



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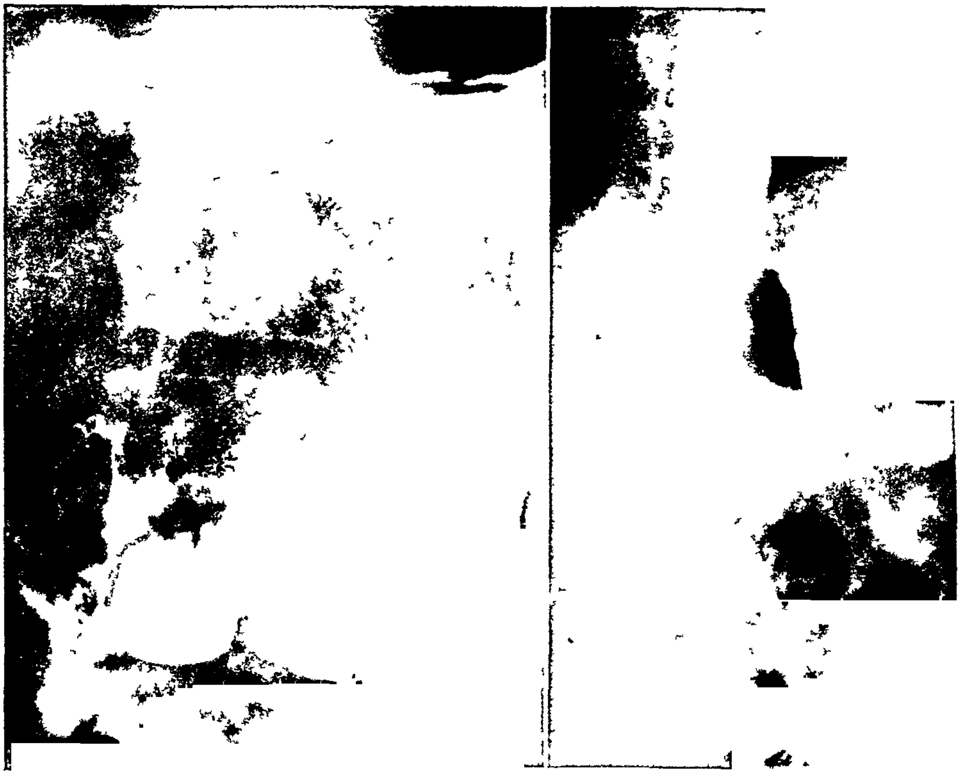
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mucous membrane can be lifted from its coverings as an intact tube Second, although it may be possible, in the presence of a short stenosis, to reduce a sliding hernia, competence of the cardia is not thereby attained, for this depends, not only on the position of the cardia in relation to the diaphragmatic crus, but also on the soft compliance of all layers of the esophagus at the junction of this with the stomach The presence of induration or fibrous scarring at the cardia, with the inability of the walls to collapse in response to very light pressure, will allow reflux into the esophagus with all that that entails even though the cardia is in its normal relation to the diaphragm The operation therefore consists of resection of the submucous stricture from beneath the muscle layers

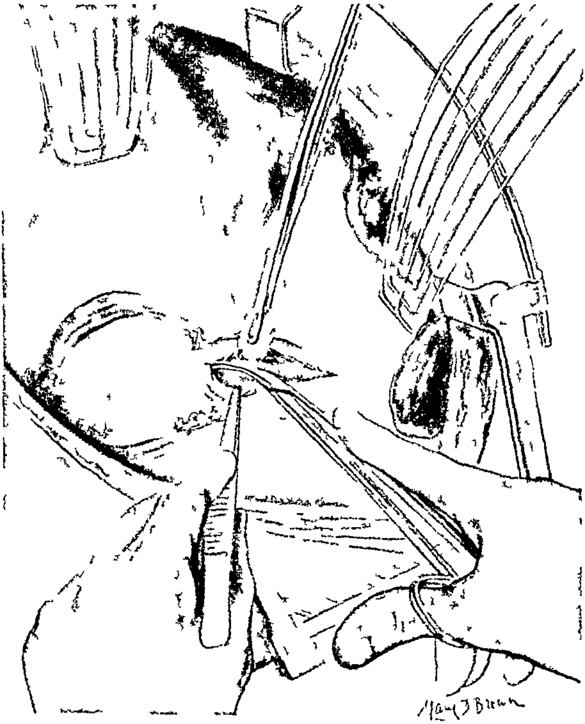

Fig. 11 —Incision of the muscular coat of the esophagus above a stricture and its separation from the mucous membrane

Through a left thoracotomy incision the esophagus and stomach are isolated within the mediastinum, leaving the vagus nerves adherent They are repair of hiatal hernia, and a gastrostomy was performed. This last was to allow aspiration of the stomach in the immediate postoperative period, for some of the vagal fibers had been cut and others almost certainly injured. The patient had a little dysphagia in the first few days after operation, intermittent slight dysphagia for solid meat during the next two months, and since then has been completely free from trouble. Dr. A. S. Johnstone examined him radiographically one year after operation, and found slight kinking at the anastomosis, no ulcer, no obstruction, and only occasional slight reflux with compression of the abdomen (Fig. 13).

Mr. G. H. Wooler has had a similar patient in whom he resected the cardia and anastomosed the esophagus to the stomach, joining the mucous membranes as far down the lesser curvature as he could, and then burying the abdominal esophagus in a tunnel of gastric muscle. Although the patient developed some fibrous stenosis, this gradually stretched until he could eat a full meal in comfort, and no reflux into the esophagus occurred.

Short Esophageal Stenosis Associated With Hiatal Hernia.—A short stenosis is taken to mean anything from a fine web to something under 1 cm. in length. Some of these strictures are obviously of the same morbid anatomy as the long ones, that is, an accumulation of inflammatory cells and fibrous tissue mainly in the submucous layer of the esophagus. There are others, however, the occurrence of which has been stressed by Ingelfinger and Kramer[1] and by Schatzki and Gary[2] and called the lower esophageal ring, where the pathology may be slightly different. A surgical approach and findings at operation in 2 patients have recently been described by Bugden and Delmonico.[3] These obstructions are of a diaphragm-like appearance, concentric, and of a constant diameter. They occur at the lower end of the esophagus and, in the patients so far observed, are associated with a sliding diaphragmatic hernia. As the symptoms in these patients are not always very severe and may, in fact, with proper mastication, be absent altogether, there has been no indication to operate upon many of them, so that the detailed pathology of the condition is still a matter for discussion. Their association with diaphragmatic hernia makes it difficult to dissociate them from esophagitis and the author's suggestion is that they resemble the webs seen in the cricopharyngeal region and that they occur by the coalescence of kissing superficial ulcers with attentuation of the fine granulations by movement, and ultimate replacement by fibrous tissue and an epithelial overgrowth. If this were true, they would differ from the short fibrous stenosis in that they result from superficial inflammation only, whereas the short fibrous stenosis results from the penetration of inflammatory processes into the submucous layer of the esophagus. The position may be a little more complicated than this for, in some patients operated upon by the author, there has been unmistakable evidence in the stricture of smooth muscle hypertrophy with or without admixture with fibrous tissue, and this in the absence of hypertrophy above the obstruction.

The surgical approach to the problem does not differ in character whether the patient presents a web obstruction or a short fibrous stenosis. It is based upon two conceptions. First, it is true that the muscular wall of the esophagus separates very easily from the mucous layer. If a longitudinal incision be made in the muscle and blunt dissection be carried out in the submucous layer, the mucous membrane can be lifted from its coverings as an intact tube. Second, although it may be possible, in the presence of a short stenosis, to reduce a sliding hernia, competence of the cardia is not thereby attained, for this depends, not only on the position of the cardia in relation to the diaphragmatic crus, but also on the soft compliance of all layers of the esophagus at the junction of this with the stomach. The presence of induration or fibrous scarring at the cardia, with the inability of the walls to collapse in response to very light pressure, will allow reflux into the esophagus with all that that entails even though the cardia is in its normal relation to the diaphragm. The operation therefore consists of resection of the submucous stricture from beneath the muscle layers.

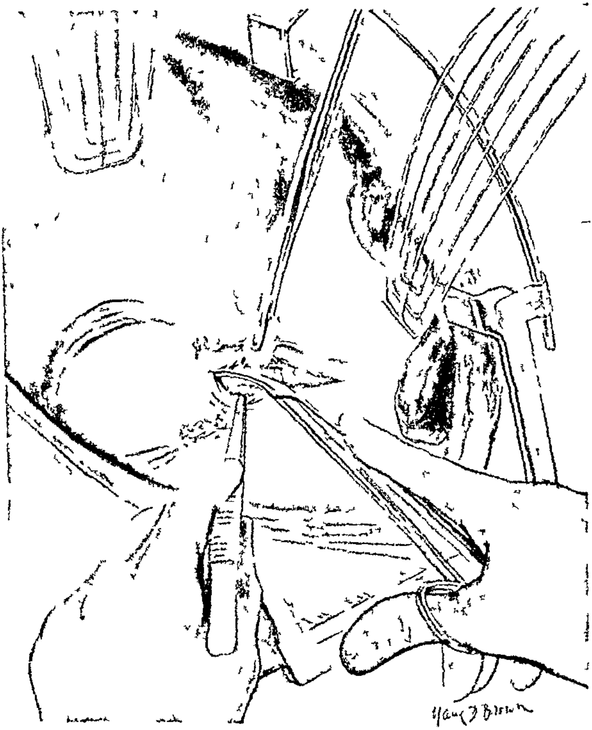

Fig. 14 —Incision of the muscular coat of the esophagus above a stricture and its separation from the mucous membrane

Through a left thoracotomy incision the esophagus and stomach are isolated within the mediastinum, leaving the vagus nerves adherent. They are rotated forward and a longitudinal incision made in the posterior wall starting 2 cm. above the cardia and passing upward for 3 cm. The incision passes down to the submucous layer; small retracting stitches are placed through the edge of the muscle, and blunt dissection carried out with fine scissors until the tube of mucous membrane is free all the way round. A string is then passed round the mucous membrane and gentle traction applied to lift it out of its bed while the incision in the muscle coat is carried down very carefully over the cardia on to the stomach. This prolongation of the incision is made with fine curved blunt-ended scissors which, in their opening action are used for blunt dissection in the submucous layer, and in their closing action cut the muscle layer. In this way the stricture is exposed (Figs. 14 and 15). It may be excised in whole or in part according to the findings at operation. The mucous membrane can sometimes be left intact but, if injured or excised, it can be repaired with fine interrupted catgut stitches. Complete hemostasis is secured and the muscle layers lightly sutured back into place. The hernia may then be reduced, the fascial connection of the cardia repaired below the diaphragm and the hiatus closed lightly around the cardia.

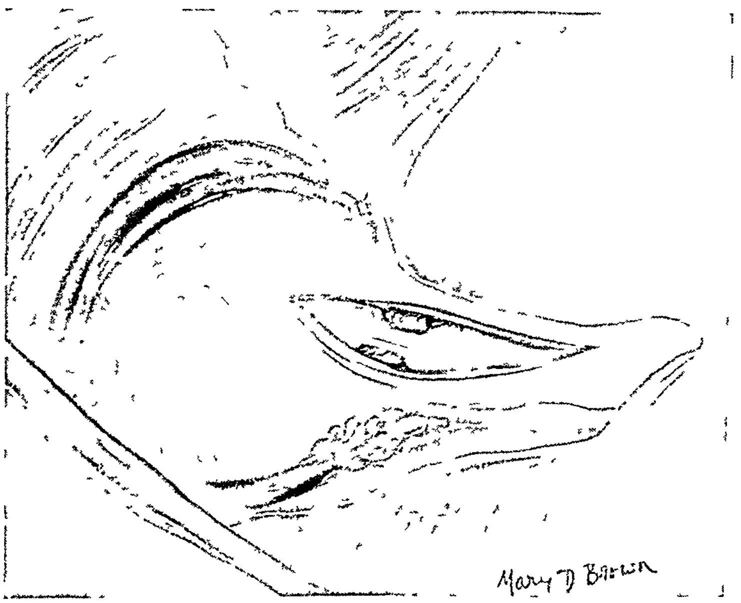

Fig. 15.—Preliminary section removed from the stricture without injury to the mucosa.

Case 6.—H. H., a man aged 59, complained of dysphagia for eight weeks. Food lodged at the lower end of the sternum causing discomfort but no pain. Regurgitation was most marked when riding in a bus after breakfast. The patient was very fat and short of breath but there were no abnormal physical findings. Radiography showed a ringlike stenosis at the lower end of the esophagus (Fig. 16). It was tight and short, and immediately below it was a pouch of herniated stomach (Fig. 17). The rest of the stomach and duodenum was normal. Esophagoscopy was difficult because of a very rigid back, but no superficial esophagitis was seen. At the lower end, a soft ulcerated stricture was seen partly obscured from above by edematous folds of esophageal mucosa. A biopsy from the stricture showed stratified squamous epithelium partly covering scarred connective tissue stroma. Operation was performed on Sept. 29, 1954, as already described. As so often happens, the exact level of the stricture could not be determined from the outside, and as a rather imperfect view had been obtained through the esophagoscope, a stomach tube was passed This became impacted 2 cm. above the apparent cardia at the level where the phreno esophageal ligament was reflected from the surface of the esophagus When the muscle layer had been separated, a thick ring of fibrosed muscle was found at the site of the stricture A section of this was excised over about one half the circumference of the esophagus and sent for histology It showed smooth muscle with some fibrous tissue replacement and a few nerve fibers. The mucosa was opened so that the inside could be inspected There was superficial ulceration at the site so that the exact position of the gastric mucosa could not be determined A biopsy above the stricture showed stratified squamous epithelium; at the stricture there was connective tissue with fibrosis and chronic inflammation, a little smooth muscle, and a fragment of squamous epithelium, and below the stricture edematous connective tissue Much fat was excised from the cardia, and the hernia treated A temporary gastrostomy was performed so that the stomach could be kept aspirated after operation. The patient was completely relieved and a barium examination two months later showed no obstruction, no dilatation, the cardia in its proper position, and no reflux (Fig 18).

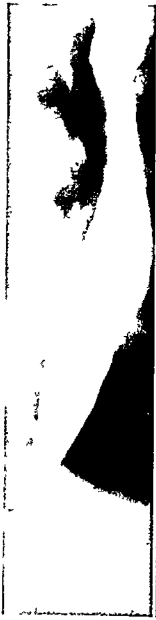
Fig 16

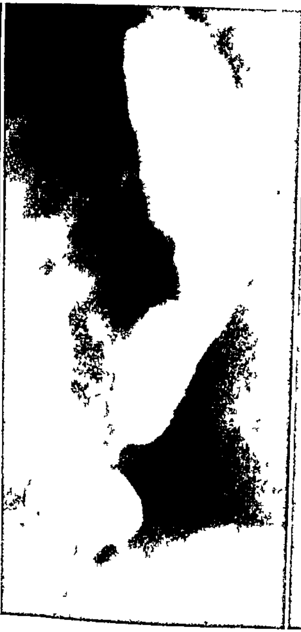
Fig 17

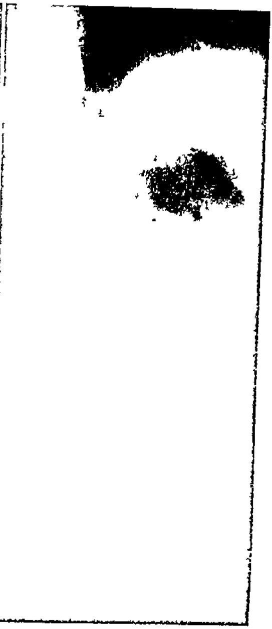
Fig 18

Fig 16—Case 6 Radiograph which shows weblike obstruction of the lower end of the esophagus associated with sliding hiatal hernia

Fig 17—Case 6 A herniated stomach, not demonstrated on the previous film, is now clearly visible

Fig 18—Case 6 A postoperative film There is still slight ring formation present above cardia but this area expanded readily to the passage of a bolus and in the absence of reflux seems unlikely to deteriorate.

Case 7.—S L, a man aged 55, had dysphagia for fifteen years and radiographs showed a ringlike constriction at the lower end of the esophagus (Fig. 19), and a sliding hernia, with the cardia 5 cm. above the hiatus. At esophagoscopy the obstruction looked like a web through which a small swab could be passed and withdrawn. As this was done, the web was pushed down or dragged up by the swab and was felt to be very resilient. An operation similar to that described above was performed. The presence of a hernia was confirmed (see Fig. 14). There was no hypertrophy of the muscle above the stricture and the obstruction itself was found to be caused by a thickened band of circular muscle immediately above the stomach, 7 mm. long and 3 to 4 mm. on cross section (see Fig. 15). It felt slightly fibrous when cut, but histologic examination showed only hypertrophied smooth muscle. The hernia was reduced. The patient remained free from symptoms and the cardia was shown to be competent when examined radiographically (Fig. 20).

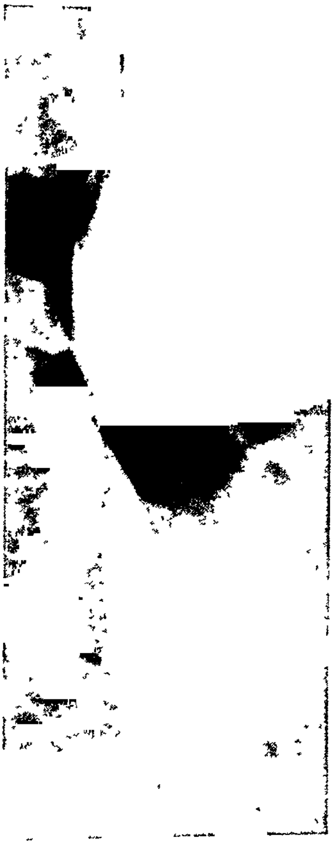

Fig. 19.

Fig. 20

Fig. 19.—Case 7. Lower esophageal ring.

Fig. 20.—Case 7. Radiograph which shows appearance after operation. No obstruction and no reflux.

Case 8.—B. B., a woman aged 56, had had severe heartburn and vomiting with each of three pregnancies. After that she had no discomfort until the age of 47 when she had pneumonia followed by heartburn and epigastric discomfort. After a strangulated inguinal hernia at the age of 52, she complained of persistent epigastric and retrosternal pain going through to the back but not related to swallowing, attacks of vomiting which was often intensely acid, and dysphagia for solid food that had not been very well masticated. Radiography showed a sliding hiatal hernia with some rigidity of the lower end of the esophagus (Fig. 21). Although fluid barium passed through easily, this part did not dilate like the rest of the esophagus. The lowest 4 cm. of the esophagus was seen at esophagoscopy to be red-raw. Just above the mucous membrane of the herniated stomach, there was a crescentic fold on the posterior wall. It was tough but short and a swab could be felt to flip over it.

The operation already described was performed for this patient. There was no obvious hypertrophy of the muscle of the esophagus. Lying transversely in the submucous layer immediately above the cardia, and corresponding to the fold seen at esophagoscopy, was a pale cream colored structure looking like a cylinder of rolled-up fibrin. It was firm to the touch and separated from the overlying muscle and adjacent areolar tissue with great ease. Its surface seemed quite smooth. It was removed without injury to the mucous membrane, and on histologic section was seen to be a mixture of fibrous tissue and smooth muscle with a whorled arrangement reminiscent of a uterine fibroid. The hernia was reduced and the patient remains free from symptoms with a competent cardia.

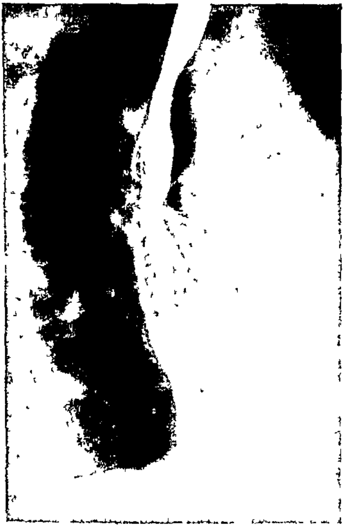

Fig. 21.—Case 8 Radiograph which demonstrates sliding hernia with rigidity of the lower end of the esophagus.

Medium-Length Esophageal Stenosis Associated With Hiatal Hernia.—A medium-length stenosis is considered as one between 1 and 2 cm. long. In this group only one patient has been treated by the author by submuscular resection of the stenosis. The operation was performed as described for short stenosis except that, when the muscular coats had been reflected, the stricture was completely excised and the mucous membrane of the esophagus united to that of the stomach by a row of fine interrupted catgut sutures. A more extensive mobilization of the esophagus was necessary in order to replace the cardia below the diaphragm. Unfortunately, this patient had bullous emphysema of both lungs with severe respiratory incapacity and he died from acute cor pulmonale eight days after operation. The respiratory difficulty was the stimulus to try to do a conservative operation for it was thought that with the aid of a tracheostomy he might survive this whereas he would not tolerate a major resection with esophagojejunostomy. No conclusions can be drawn from this as reasons; 15 patients received only a few treatments in our department and then left the hospital to be treated in other cities, 2 patients with pleural effusion were treated with radiogold, and 7 patients had excellent clinical evidence of bronchogenic carcinoma but the diagnosis was not proved histologically. Thus, there remained 50 proved cases of bronchogenic carcinoma for study. All 50 of these patients were treated on a 400 kv. constant potential x-ray generator. The half-value-layer of the beam was 6.5 mm. Cu. With a beam of this quality, 5,000 to 6,000 r can be delivered to the tumor through two or three ports.

The 50 cases were divided into histologic groups as shown in Table I.

TABLE I. HISTOLOGIC DISTRIBUTION OF CASES

Undifferentiated carcinoma	20
Squamous-cell carcinoma	18
Adenocarcinoma	3
Malignant but cell type unknown	9

UNDIFFERENTIATED CARCINOMA

Analysis of the undifferentiated group comprising 20 patients proved the ineffectiveness of treatment of this type of bronchogenic carcinoma (Table II).

TABLE II. UNDIFFERENTIATED CARCINOMA GROUP

Number of patients in group	20
Number of patients followed	18
Number of patients dead	17
Number of patients living	1
Number of one-year survivals	0
Percentage of cases surviving one year	0%
Number of patients with metastases before treatment	9
Percentage of patients with metastases before treatment	45%
Average survival time of dead patients in months	4.7

The average age of this group was 55 years. The average duration of time between the onset of symptoms and the diagnosis was 2.4 months. Node metastases outside of the thorax were present at the time of diagnosis in 9 of these 20 patients, or 45 per cent. Not a single one of these patients survived over eleven months. The average survival time for the 17 patients who are known to be dead was only 4.7 months. One patient is still alive three months after treatment and 2 of the cases have no follow-up information but both were in very poor condition at the completion of their treatment and they are presumed to be dead. Five patients received over 5,000 r tumor dose, four received between 4,000 and 5,000 r, six received 3,000 to 4,000 r, and the remaining 5 received less than 3,000 r tumor dose. The average survival time of the patients receiving more than 5,000 r was 4.8 months which is almost identical to the average survival of the entire group; therefore, it appears that there is in our series no demonstrable correlation between total dose and survival time in this group.

SQUAMOUS-CELL CARCINOMA

The results obtained by the radiation treatment of this group with squamous-cell carcinoma was more encouraging than the preceding one (Table III). The average age of this group was identical with that of the undifferentiated group. The average duration of time between the onset of symptoms and the diagnosis was 2 9 months which is similar to the undifferentiated group Known metastases outside of the thorax were present in only 11 per cent of this group as compared to 45 per cent in the anaplastic group Fifteen of the 18 patients are dead and 8 of these survived longer than one year The percentage of one year survival among the dead patients was 53 per cent The average survival time of the deceased patients was 11 4 months This is approximately seven months longer than the average survival time for the deceased members of the preceding group Four of the dead patients survived eighteen months and 1 survived twenty four months There is a two and one half year survival among the 3 living patients and the remaining 2 are alive eleven months and four months posttherapy, respectively

TABLE III SQUAMOUS CELL CARCINOMA GROUP

Number of patients in group	18
Number of patients followed	18
Number of patients dead	15
Number of patients living	3
Number of one year survivals among dead	8
Percentage of patients dead surviving over one year	53%
Number of patients living and dead surviving one year	9
Percentage of patients living and dead surviving one year	50%
Number of patients living and dead surviving 18 months	5
Percentage of patients living and dead surviving 18 months	28%
Number of patients living and dead surviving 24 months	2
Percentage of patients living and dead surviving 24 months	11%
Number of patients with metastases before treatment	2
Percentage of patients with metastases before treatment	11%
Average survival time of dead patients in months	11 4

Seven of the 18 patients received over 5,000 r tumor dose, 7 received between 4,000 r and 5,000 r, 1 received between 3,000 r and 4,000 r, and the remaining 3 received less than 3,000 r It is difficult to draw any conclusion concerning the relationship between total doses and survival time in any series of cases because there are many immeasurable factors which affect survival time Among these factors are the extent of the tumor, the presence of metastases, the location of the tumor, and the condition of the patient Dosage rate is another measurable factor which is as important as total dose, yet, it is completely ignored when survival time is plotted against total dose Because of these factors, the conclusion that the survival time among patients treated with doses in excess of 5,000 r was 14 1 months while the over all survival time for the whole group was 11 4 months is of doubtful significance

ADENOCARCINOMA

The average survival time for this group was 8 3 months No other fact is worth mentioning because of the small size of this group

HISTOLOGICALLY UNKNOWN GROUP

The survival time in this group of 9 patients was only 4 6 months This is as poor as the undifferentiated group The reason for this poor survival is not apparent but it is probably due to the fact that many of these patients were in very poor condition when seen and the diagnosis had to be made on the microscopic examination of the bronchial smears reasons; 15 patients received only a few treatments in our department and then left the hospital to be treated in other cities, 2 patients with pleural effusion were treated with radiogold, and 7 patients had excellent clinical evidence of bronchogenic carcinoma but the diagnosis was not proved histologically. Thus, there remained 50 proved cases of bronchogenic carcinoma for study. All 50 of these patients were treated on a 400 kv. constant potential x-ray generator. The half-value-layer of the beam was 6.5 mm. Cu. With a beam of this quality, 5,000 to 6,000 r can be delivered to the tumor through two or three ports.

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The average age of this group was 55 years. The average duration of time between the onset of symptoms and the diagnosis was 2.4 months. Node metastases outside of the thorax were present at the time of diagnosis in 9 of these 20 patients, or 45 per cent. Not a single one of these patients survived over eleven months. The average survival time for the 17 patients who are known to be dead was only 4.7 months. One patient is still alive three months after treatment and 2 of the cases have no follow-up information but both were in very poor condition at the completion of their treatment and they are presumed to be dead. Five patients received over 5,000 r tumor dose, four received between 4,000 and 5,000 r, six received 3,000 to 4,000 r, and the remaining 5 received less than 3,000 r tumor dose. The average survival time of the patients receiving more than 5,000 r was 4.8 months which is almost identical to the average survival of the entire group; therefore, it appears that there is in our series no demonstrable correlation between total dose and survival time in this group.

SQUAMOUS-CELL CARCINOMA

The results obtained by the radiation treatment of this group with squamous-cell carcinoma was more encouraging than the preceding one (Table III). The average age of this group was identical with that of the undifferentiated group. The average duration of time between the onset of symptoms and the diagnosis was 2.9 months which is similar to the undifferentiated group. Known metastases outside of the thorax were present in only 11 per cent of this group as compared to 45 per cent in the anaplastic group. Fifteen of the 18 patients are dead and 8 of these survived longer than one year. The percentage of one year survival among the dead patients was 53 per cent. The average survival time of the deceased patients was 11.4 months. This is approximately seven months longer than the average survival time for the deceased members of the preceding group. Four of the dead patients survived eighteen months and 1 survived twenty four months. There is a two and one half year survival among the 3 living patients and the remaining 2 are alive eleven months and four months posttherapy, respectively.

TABLE III. SQUAMOUS CELL CARCINOMA GROUP

Number of patients in group	18
Number of patients followed	18
Number of patients dead	15
Number of patients living	3
Number of one year survivals among dead	8
Percentage of patients dead surviving over one year	53%
Number of patients living and dead surviving one year	9
Percentage of patients living and dead surviving one year	50%
Number of patients living and dead surviving 18 months	5
Percentage of patients living and dead surviving 18 months	28%
Number of patients living and dead surviving 24 months	2
Percentage of patients living and dead surviving 24 months	11%
Number of patients with metastases before treatment	2
Percentage of patients with metastases before treatment	11%
Average survival time of dead patients in months	11.4

Seven of the 18 patients received over 5,000 r tumor dose, 7 received between 4,000 r and 5,000 r, 1 received between 3,000 r and 4,000 r, and the remaining 3 received less than 3,000 r. It is difficult to draw any conclusion concerning the relationship between total doses and survival time in any series of cases because there are many immeasurable factors which affect survival time. Among these factors are the extent of the tumor, the presence of metastases, the location of the tumor, and the condition of the patient. Dosage rate is another measurable factor which is as important as total dose, yet, it is completely ignored when survival time is plotted against total dose. Because of these factors, the conclusion that the survival time among patients treated with doses in excess of 5,000 r was 14.1 months while the over all survival time for the whole group was 11.4 months is of doubtful significance.

ADENOCARCINOMA

The average survival time for this group was 8.3 months. No other fact is worth mentioning because of the small size of this group.

HISTOLOGICALLY UNKNOWN GROUP

The survival time in this group of 9 patients was only 4.6 months. This is as poor as the undifferentiated group. The reason for this poor survival is not apparent but it is probably due to the fact that many of these patients were in very poor condition when seen and the diagnosis had to be made on the microscopic examination of the bronchial smears.

COMMENT

From the statistics presented here there is no doubt that the survival time following radiation therapy is much longer for squamous-cell carcinoma of the lung than for undifferentiated carcinoma (Fig. 1). The average survival time is

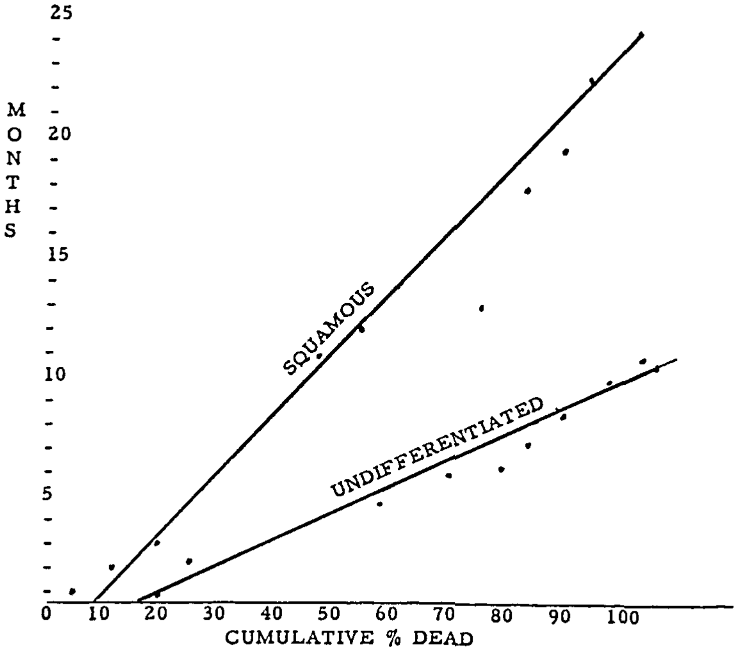

Fig. 1.—A graph demonstrating the rapidity of death in patients with undifferentiated carcinoma compared with the patients with squamous-cell carcinoma.

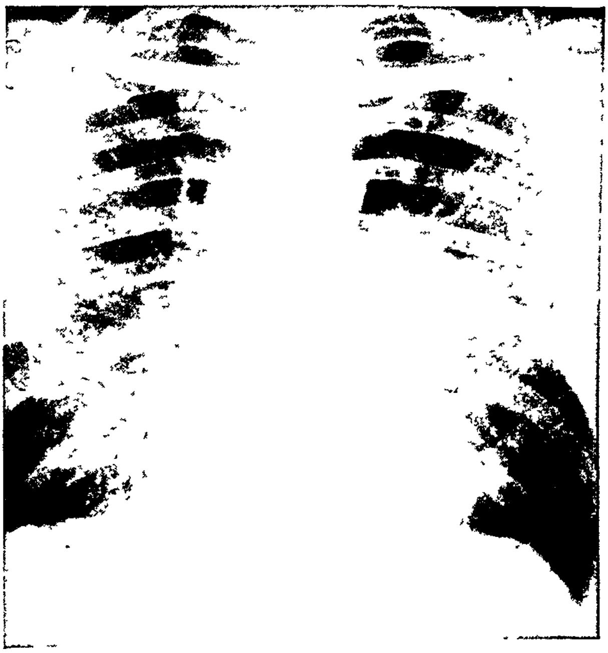

Fig. 2.—Chest roentgenogram of patient with undifferentiated carcinoma demonstrating the tumor before treatment. There is involvement of the central portion of the left lung and a rounded mass protruding from the right side of the mediastinum at the level of the aortic arch.

over twice as long for the squamous cell group as it is for the anaplastic group The one-year survival rate is 0 per cent for undifferentiated carcinoma and 53 per cent for the squamous cell lesions The eighteen-month survival rate

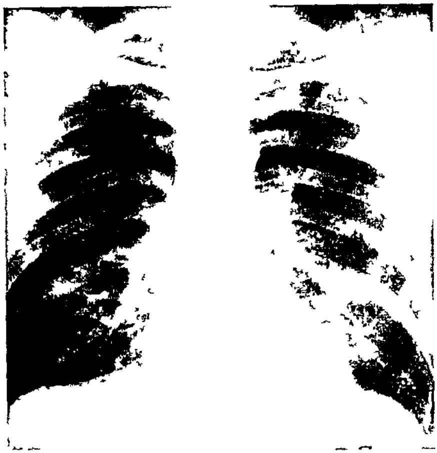

Fig 3 —Chest appears normal after 3,471 r had been delivered to the tumor in fifty days

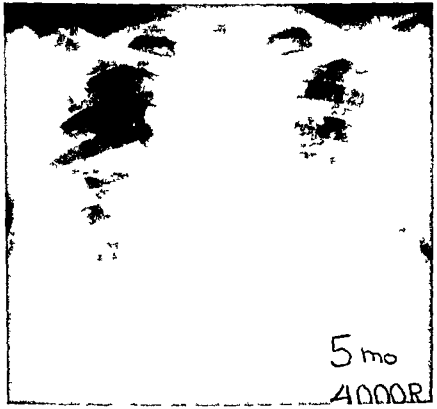

Fig 4 —Roentgenogram taken five months after treatment Tumor has recuperated and is now growing wildly throughout the chest

for squamous cell carcinoma is 27 per cent Although we did not have a control group of untreated cases, the literature has many reports of control groups and few patients with bronchogenic carcinoma survive one year after diagnosis without any form of therapy The fact that we obtained a 53 per cent one-year survival rate after treatment indicates that squamous-cell lesions are benefited by radiation therapy. It would then seem to follow that the treatment of squamous-cell carcinoma by radiotherapy should be carried out as vigorously as possible. This does not hold true for the undifferentiated lesions. The survival time in this group is very poor and it is doubtful that radiation therapy increases the survival time. There are three factors which account for the poor prognosis in anaplastic carcinoma:

1. They metastasize early as illustrated by the presence of metastases outside of the thorax in 45 per cent of the cases treated.
2. They are rapidly growing and by nature extremely invasive.
3. Although radiosensitive, they are also rapidly recuperable (Figs. 2, 3, 4).

SUMMARY

Vigorous radiotherapy to squamous-cell carcinoma of the lung is justified by the increased survival time in treated patients. On the other hand, radiotherapy of undifferentiated carcinoma should be reserved for the localized inoperable lesion and it is of doubtful value even in this selected lesion.

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A DIRECT EXPERIMENTAL APPROACH TO THE AORTIC VALVE
II. ACUTE RETROPERFUSION OF THE CORONARY SINUS

GUMERSINDO BLANCO, M.D., ALBERTO ADAM, M.D., AND AGUSTÍN FERNÁNDEZ, B.S.
SAN JUAN, PUERTO RICO

DIRECT or "open" intracardiac surgery has evolved very rapidly within the past five years. During this period it has made the important transition from a limited experimental approach to a widely applicable clinical procedure.[1]

Two basic techniques have been developed by workers who endeavor to operate within the heart and correct congenital defects or acquired valvular lesions, under direct exposure.

The first technique employs the use of hypothermia to lower the metabolic needs of the body. In this way the cardiac pump action can be dispensed with temporarily and the circulation stopped during the intracardiac operative episode.[3,4] Under these circumstances the surgeon has a limited time for intracardiac manipulations.[5,6] After this, the cardiac pump action must be restored if the metabolic debt is to be reversible, and the vital organs are to survive. Aside from the time limitation, hypothermia is frequently attended by certain side effects which have been considered undesirable. The most important of these is ventricular fibrillation. Intensive research is under way in order to gain a more adequate understanding of the body reactions in hypothermia and, also, to devise means of preventing and treating these undesirable phenomena.

The second "open" technique is one in which the heart and lungs of a normothermic subject are by passed by a mechanical pump oxygenator [illegible] by the heart and lungs of a donor[10] (cross circulation) and the greater [illegible] as the coronary circulation are supported by an aortic perfusion of [illegible] blood (from pump oxygenator or donor) at adequate pressures.

None of these techniques has achieved isolation of the heart in [illegible] By this we mean complete independence of this organ from the greater [illegible] perfusion system.

Again, none of these methods has succeeded in allowing [illegible] the region of the aortic valve with impunity. Entrance into [illegible] exposes the coronary ostia to the free air with resulting [illegible] ventricular fibrillation, and death. If entry is attempted [illegible] fusion is going on, immediate death would result from [illegible] loss of perfusion pressure.

From the Department of Surgery and the Experimental [illegible] Medicine University of Puerto Rico San Juan Puerto Rico.

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A DIRECT EXPERIMENTAL APPROACH TO THE AORTIC VALVE

II ACUTE RETROPERFUSION OF THE CORONARY SINUS

Gumersindo Blanco, M D , Alberto Adam, M D , and Agustín Fernández, B S
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DIRECT or "open" intracardiac surgery has evolved very rapidly within the past five years During this period it has made the important transition from a limited experimental approach to a widely applicable clinical procedure[1, 2]

Two basic techniques have been developed by workers who endeavor to operate within the heart and correct congenital defects, or acquired valvular lesions, under direct exposure

The first technique employs the use of hypothermia to lower the metabolic needs of the body In this way the cardiac pump action can be dispensed with temporarily and the circulation stopped during the intracardiac operative episode[3, 4] Under these circumstances the surgeon has a limited time for intracardiac manipulations[5, 6] After this, the cardiac pump action must be restored if the metabolic debt is to be reversible, and the vital organs are to survive Aside from the time limitation, hypothermia is frequently attended by certain side effects which have been considered undesirable The most important of these is ventricular fibrillation Intensive research is under way in order to gain a more adequate understanding of the body reactions in hypothermia[7] and, also, to devise means of preventing and treating these undesirable phenomena

The second "open" technique is one in which the heart and lungs of a normothermic subject are by passed by a mechanical pump oxygenator,[8, 9] or by the heart and lungs of a donor[10] (cross circulation), and the greater as well as the coronary circulation are supported by an aortic perfusion of arterial blood (from pump oxygenator or donor) at adequate pressures

None of these techniques has achieved isolation of the heart in vivo By this we mean complete independence of this organ from the greater circulation perfusion system

Again, none of these methods has succeeded in allowing an approach to the region of the aortic valve with impunity Entrance into this region exposes the coronary ostia to the free air with resulting coronary air embolism, ventricular fibrillation, and death If entry is attempted while aortic perfusion is going on, immediate death would result from massive bleeding and loss of perfusion pressure

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During the past year, a series of experiments[11] has been carried out in this laboratory with the aim of developing a technique whereby the following criteria were satisfied:

1. Isolation of the heart from the greater circulation. This involves maintenance of the greater and of the coronary circulation by independent means.
2. Development of a technique whereby entrance into the region of the aortic valve and exposure of the coronary ostia would not be accompanied by air embolism.

This report concerns the development of a method which meets these criteria successfully. It makes use of procedures which have been widely known and accepted for many years as well as of others of relatively recent vintage. The greater circulation is maintained throughout by the employment of a cross circulation setup very similar to the one described by Lillehei and his colleagues[10] and the use of information (regarding volume of perfusion) collected by Andreasen and Watson.[12] The coronary circulation is maintained by the application of principles based on observations by Pratt,[13] Roberts[14] and Beck and co-workers[15] to the effect that successful perfusion of the myocardial capillary bed can be carried out through retroperfusion of the coronary sinus.

The observation of retrograde flow in the coronary arteries, in such a coronary sinus retroperfusion preparation, has been made by Eckstein,[16] and by Bakst, Adam, Goldberg, and Bailey.[17] It has been used as a measure of the success of myocardial perfusion. These observations warranted the assumption that if such a retrograde flow occurred, exposure of the coronary ostia during sinus retroperfusion would be innocuous from the standpoint of the occurrence of air embolism. This assumption is borne out by the present work.

METHOD

Three adult mongrel dogs were anesthetized by the administration of 30 mg. of Nembutal, per kilogram of weight, intravenously. Intratracheal intubation was performed on all 3 animals and they were connected to mechanical respirators. Catheterization of peripheral blood vessels was carried out as follows:

Dog A (Subject): No. 10 Fr. plastic "oxygen" catheters were introduced into the right carotid artery and into the right external jugular and femoral veins. The tips of the venous catheters were placed about 3 cm. away from the entrance of the superior and inferior venae cavae into the right atrium.

Dog B (Donor No. 1): No. 10 Fr. plastic "oxygen" catheters were placed in the right (or left) femoral artery and vein.

Dog C (Donor No. 2): A No. 10 Fr. plastic "oxygen" catheter was placed in the right (or left) femoral artery.

All catheters were filled with heparin solution, clamped, and secured in place.

A right thoracotomy incision through the fourth or fifth intercostal space was performed on Dog A, and the cardiac inflow tracts were controlled by ligation of the azygos vein in continuity, and by-passing tapes around the superior and inferior venae cavae near their entrance into the right atrium, proximal to the tips of the aforementioned venous catheters. The aorta was dissected free just above its origin so that it might be cross clamped about 5 to 6 cm. above the valvular level. A purse-string suture was placed around the tip of the right auricular appendage and a short plastic catheter introduced through the tip of the appendage and directed with the aid of a guide into the coronary sinus. Its tip came to lie about 1.5 cm. inside the sinus, the guide was withdrawn and the catheter was anchored in place by tying the aforementioned purse-string suture, and by placing an encircling ligature around the coronary sinus and its indwelling catheter, distal to the entrance of the sinus into the right atrium. The catheter was filled with heparin solution and clamped (See Fig. 1).

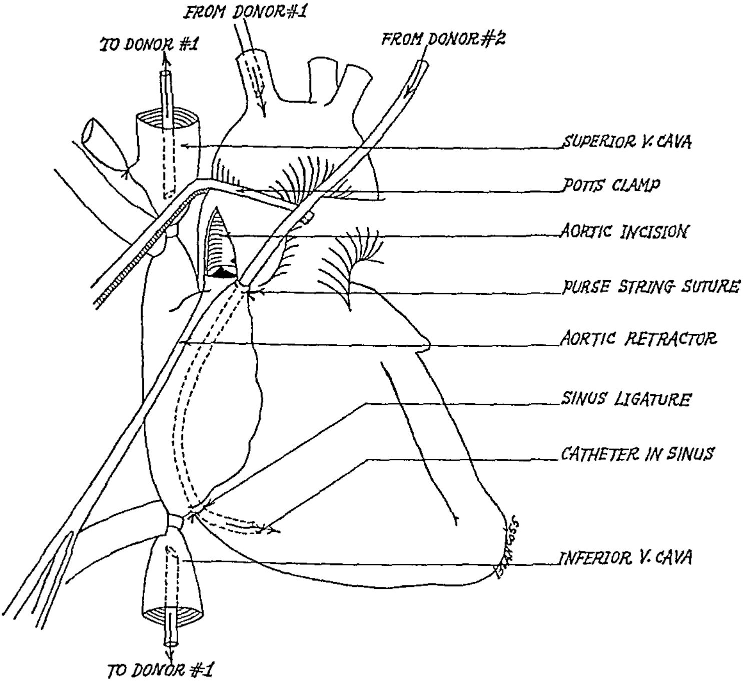

Fig. 1.

Dogs A and B were then joined by a cross circulation setup powered [illegible] a double Sigmamotor pump, in which venous blood was extract[illegible] I via the catheters placed in the external jugular and [illegible] v

the cross circulation was stopped, the cardiac inflow tract was released, and the lungs were re-expanded followed by connection of the intratracheal tube to the mechanical respirator.

The coronary sinus catheter was pulled out, and the tip of the auricular appendage was ligated The aorta was inspected for evidences of bleeding The pleural cavities were sucked dry. The chest was closed in layers leaving a No 18 Fr. rubber catheter, with multiple holes, in the chest to be attached to suction during the immediate postoperative period. Electrocardiographic tracings of Dog A were taken before and after the operative procedure. They were repeated twenty-four hours after the operation

DISCUSSION

During the preliminary stages of this project, 20 dogs were operated upon and various modifications of approach, times of inflow occlusion, and intra-aortic maneuvers, were tried Many of the experiments were acute in nature and, in many, the aorta was left open as long as the heart was beating regularly in order to determine the maximum time available for direct valvular manipulation. As can be expected, the mortality was extremely high in this group and only 3 animals survived these procedures

After our present approach was perfected 11 dogs were operated upon, and these comprise the series which concerns this report. The time during which the animals were kept on cross circulation, the time spent in intra-aortic maneuvers, and the survival rates are detailed in Table I

TABLE I DATA ON CROSS CIRCULATION, AND INTRA AORTIC VISUALIZATION TIMES, AND ON SURVIVALS

DOG	TIME ON CROSS CIRCULATION (MIN)	TIME FOR INTRA AORTIC MANEUVERS (MIN)	SURVIVAL (4 OR MORE DAYS)
S21	14	3½	Survived
S22	17	6	Survived
S23	-	-	Died at operation
S24	12	5½	Survived
S25	11½	4¾	Survived
S26	16½	6¼	Survived
S27	15½	7¼	Survived
S28	14	4	Died 24 hours
S29	14	6	Survived
S30	16	7	Survived
S31	16	7	Survived

One dog (S23) died on the operating table from a preventable error. In this animal, the coronary sinus catheter became dislodged, and upon attempting to replace it undue force was used and the metal guide used for placing it penetrated the ventricular myocardium, and perforated the ventricle Perfusion with the catheter in the myocardium was unsuccessful and ventricular fibrillation followed

Another dog (S28) died twenty-four hours after the procedure was completed In this animal, considerable trouble was experienced with the cross circulation setup, presumably because of clotting in the connecting tubing, with jected into Dog B's femoral vein. Arterial blood was returned from Dog B into Dog A's carotid artery. The pumps had been previously set to deliver approximately 200 c.c. of blood per minute.

After these connections were made, taking care to eliminate all air bubbles from the system, the cardiac inflow tract of Dog A was closed by tightening the tapes around both venae cavae and the pumps were started. At this point the respirator was disconnected from Dog A allowing the lungs to collapse. The cross circulation preparation was then complete.

After a brief period (1 to 2 minutes) to allow for a thorough check of all connections and assure good functioning of the cross circulation, the catheter in Dog C's femoral artery was connected to the catheter in Dog A's coronary sinus after graduating the flow through the connecting tube so that about 50 c.c. of arterial blood per minute was delivered. The clamp was taken off the coronary sinus catheter and sinus retroperfusion became evident: The epicardial veins coursing over the right ventricle became red, the heart which had become smaller and almost empty during the cross circulation period, appeared fuller.

A Potts' curved clamp was then quickly placed across the aorta about 5 cm. above its origin and, before the vessel had a chance to dilate too much, a longitudinal incision was made along its anterolateral surface. This incision was about 2 cm. in length and started just above the sinuses of Valsalva. The greater circulation was sustained at this point by the cross circulation perfusion while the myocardial circulation was sustained by retroperfusion of the coronary sinus. A small jet of blood escaped from the aortic incision and subsided as soon as the latter was enlarged. If the coronary sinus retroperfusion was successful the heartbeat was forceful and the epicardial veins maintained their bright red color.

A small retractor was inserted into the aortic incision and the superior valvular surfaces were inspected. The coronary ostia were also visualized. With the help of moderate suction the field could be kept fairly dry and exposure was good.

During this time it was well to check on the condition of Dog C and make sure that he was tolerating well the bleeding into Dog A's coronary sinus. If any weakness of Dog C's peripheral pulses was noted or if the sinus perfusion appeared to be deteriorating, as evidenced by a darkening of the epicardial veins, steps were taken to close the aortic incision and return the heart to the cross circulation perfusion system. A period of 5 minutes was well tolerated, at the end of which the incision in the aorta was closed (allowing all air to escape the left ventricle before placing the final suture) and the cross clamp was removed. This restored continuity between coronary and greater circulations. A clamp was then placed across the sinus catheter.

The epicardial veins resumed their dark color almost immediately. After a short wait of 1 to 2 minutes during which the heart was observed for any evidence of coronary air embolism, arrythmias, weakness of contraction, etc., the cross circulation was stopped, the cardiac inflow tract was released, and the lungs were re-expanded followed by connection of the intratracheal tube to the mechanical respirator

The coronary sinus catheter was pulled out, and the tip of the auricular appendage was ligated The aorta was inspected for evidences of bleeding The pleural cavities were sucked dry The chest was closed in layers leaving a No 18 Fr rubber catheter, with multiple holes, in the chest to be attached to suction during the immediate postoperative period Electrocardiographic tracings of Dog A were taken before and after the operative procedure They were repeated twenty four hours after the operation

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Another dog (S28) died twenty four hours after the procedure was completed In this animal, considerable trouble was experienced with the cross circulation setup, presumably because of clotting in the connecting tubing, with collapse of the latter, and inefficient perfusion. Intra-aortic maneuvers had to be interrupted but in spite of this, cerebral anoxia must have occurred before the cardiac inflow could be opened and breathing with the aid of the respirator carried out.

In the remaining 9 animals, adequate myocardial perfusion was obtained for periods ranging from 3½ to 7 minutes (an average of 5 minutes) during which the superior surface of the aortic cusps and the coronary ostia were inspected directly, while the aortic wound was maintained wide open by the intra-aortic retractor. There were no instances of air embolism or fibrillation and it was not necessary to employ cardiac massage or drugs to strengthen or aid the cardiac contraction at any time. We have mentioned the weakening of the pulses of the second donor dog (Dog C) as the factor that made us interrupt our perfusion in every instance. Concomitantly with this change the coronary sinus perfusion would also deteriorate, and the myocardial contraction in Dog A would falter perceptibly. It is felt that the use of more than one donor for this purpose or the use of a reservoir of oxygenated blood would prolong the time of myocardial perfusion and consequently the period available for intra-aortic maneuvers.

SUMMARY

An experimental method has been described whereby complete independence between the systemic and coronary circulations can be achieved and the two may be maintained simultaneously during total cardiac by-pass.

Retroperfusion of the coronary sinus is used to maintain the nutrition and oxygenation of the myocardium.

The method described allows entry into the aorta just above the valvular level, with direct intra-aortic visualization of the superior surfaces of the aortic ostia, without danger of coronary air embolism or other dangerous sequelae.

Eleven dogs have been operated upon by this technique with two deaths within forty-eight hours after the operation. These deaths can be attributed directly to avoidable technical errors.

It is believed that the limited time (about 7 minutes) available, at present, for intra-aortic maneuvers, can be extended substantially by feasible improvements in this method. Further experiments are being undertaken to this effect and will be the subject of future communications.

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DECORTICATION IN PRIMARY TUBERCULOUS PLEURITIS AND EMPYEMA WITH A STUDY OF FUNCTIONAL RECOVERY

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The procedure of removing a thick inflammatory tuberculous peel from the lung has been reported by many authors.[9-11, 14, 17, 18] Technically it is more difficult than decortication following traumatic hemothorax. Even if there is frank empyema, most of the wounds heal without infection and few redevelop an empyema. The majority of the previously reported cases of surgical decortication represent empyema, or inexpansible lung with residual pleural spaces, following therapeutic pneumothorax. Few have reported more than 1 to 7 cases of decortication for organized tuberculous pleuritis and empyema as a sequela to pleural effusion. Tuttle's series of 43 patients had only 7 who represented decortications for tuberculous pleuritis and effusion with encased lung.[16] No pulmonary function studies were reported. In a series of thirteen decortications reported by Falk, Pearson, and Martin, four were for sequelae of tuberculous pleurisy with effusion.[6] Function studies were reported. In a report of sixty-six decortications by the Subcommittee on Surgical Treatment of Diseases of the Chest (American College of Chest Physicians), only three were simple decortications for tuberculous empyema.[1] Results were good in two, fair in one. Fifty-one decortications performed on 49 patients with tuberculosis were reported by Ellis from the Mayo Clinic.[5] In only 1 of 7 patients with tuberculous empyema was the disease primary, in the others it resulted as a complication of an inexpansible lung after pneumothorax. One other patient underwent decortication for pleurisy with effusion but this was three years following thoracoplasty.

It is the purpose of this article to report on 16 cases of organized tuberculous pleuritis, following effusion, treated by visceroparietal decortication; no other surgical procedure being carried out in conjunction with this operation.

Patients who develop primary tuberculous pleural effusions follow one of three courses on drug therapy. The effusion may resolve rapidly with or without multiple thoracenteses. Resolution may be slow with gradual formation of a thick, fibrotic pleural peel. A more violent inflammatory reaction may produce a thick peel which in certain areas will caseate extensively and be associated with frank pus with or without a bronchopleural fistula. The latter is what is commonly accepted as tuberculous empyema. The response, we

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believe, depends chiefly upon the pathogenic vigor with which the subpleural active caseous focus seeds the pleura. The initial serous effusion may well be a transudative response to tuberculous inflammation in the subpleural lymphatics, but as the tuberculous inflammation, with its bacterial inoculum reaches the pleural space, fluid that originally is abundant, serous, of low specific gravity, and nonsanguineous often becomes thick, flocculent pus unobtainable by thoracentesis. A heavy opacity on roentgenograms in the dependent portions of the lung field results. The pleural peel often persists despite attempts at medical debridement by the use of proteolytic enzymes. Active tuberculosis is not a contraindication to their use.[14, 15] The early and efficient use of the enzymes and aspiration will make surgical decortication necessary less frequently. Fluid may become nonaspirable either because of coagulation, or because of its loculation and fibrin content. Even though all fluid may seem to disappear, the inflammatory build up of the pleural peel may continue because of the extensive caseous tuberculosis of the peel itself. The presence of such a thick membrane, with or without fluid encases the lung in an unyielding cuirass which may render the lung totally incapable of respiratory exchange.

Early, Wright showed, by bronchospirometric determinations, that following re-expansion of lung tissue and restoration of normal or near normal ventilatory function, impairment may remain in pulmonary circulatory function.[18] A barrier at the alveolar wall by histologic alteration in the collapsed segments is postulated. Uninvolved, healthy lung recovers its function in large measure. Diseased lung, initially compressed therapeutically and later released by decortication, is not likely to recover any large measure of function. This is confirmed by the outstanding work of Patton, Watson and Gaensler who showed that restoration of function after decortication was closely related to the presence or absence of pre-existing disease in lung parenchyma.[13] It may be difficult to establish the extent of destructive disease in the lung parenchyma obscured by the radiopaque pleural peel. Sputum studies, bronchoscopic and gastric washings, and tomography are of aid in estimating parenchymal involvement.

MATERIAL

Sixteen primary decortications on 15 patients were done between January, 1949, and December, 1953, and form the basis for this report. One of us, (F. J. J.) performed fifteen of the sixteen operations. In 1 patient both sides were decorticated with an interval of four weeks between operations. These were all done at Firland Sanatorium, Seattle. All of the patients operated upon had an original diagnosis of tuberculous pleural effusion resulting spontaneously and not as any therapeutic or diagnostic complication. There was minimal to moderately advanced parenchymal involvement in 10 patients, 4 of whom had positive sputum at the time of admission to the sanatorium. Seven (47 per cent) had bacteriologically positive effusions. Prior to January, 1952, streptomycin and PAS were used only during the initial preoperative postoperative period for thirty days. Seven patients were treated in

visceral pleura overlying the lung is stripped away, freeing the lung for reexpansion. The parietal pleural peel seems largely to resorb within a few weeks once the hemothorax is obliterated. In the case of the tuberculous peel, we are dealing with a much more completely organized, densely fibrous structure, covering both viscera and parietal structures. The peel itself frequently contains large areas of conglomerate caseation, more particularly as

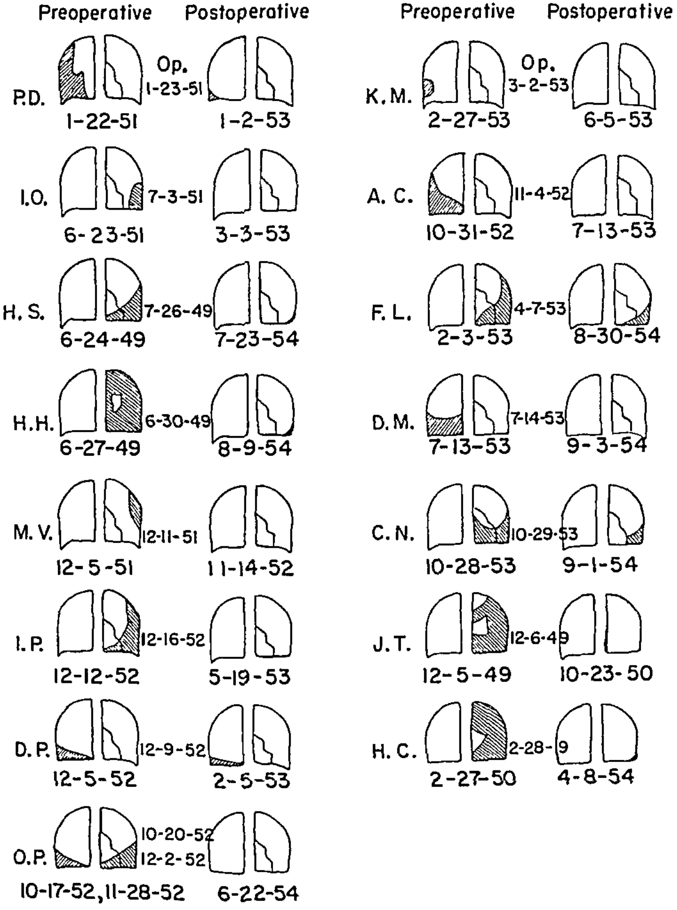

Fig. 1.—Composite drawings from preoperative and postoperative x-rays of 15 patients with tuberculous pleuritis

manner. After this date, drug treatment was started shortly after admission, continued through the surgical period until discharge and in some patients not yet concluded. Multiple aspirations were done on all patients initially until no fluid could be obtained. Seven patients underwent surgery less than six months after admission while 8 had an average interval of twelve months between admission and decortication. Eleven of the 15 patients were under 35 years of age. There was no mortality. No empyema spaces persist to our knowledge.

Specific indications for surgery were (1) persistent febrile course, (2) persistent empyema in spite of vigorous medical therapy, (3) size and extent of the encasement, (4) significant reduction of lung function, and (5) failure to improve on conservative measures. Control of the underlying parenchymal disease was considered satisfactory for the ensuing operative procedure.

RESULTS

Thirteen of the 16 patients were classed as excellent in considering only the final appearance of the roentgenograms, 2 were classified as fair, and 1, poor. Schemograms (Fig. 1) show the pre- and postoperative results by reproducing the x-ray densities in shaded areas as closely as possible.

Incomplete resolution of the radiopacity was closely related to the fair to poor postoperative courses. The correlation was, however, not exact. Significant postoperative complications occurred in 4 patients. These are stated in brief in Table I.

TABLE I

PATIENT	COMPLICATIONS	POSTOP. COURSE	X-RAY RESULTS
D. P.	Alveolopleural leak with hydropneumothorax, 8 days postop. Treatment: Reinsertion of tube	Fair	Poor
F. L.	Severe hemothorax with resultant fibrothorax despite enzymatic débridement	Poor	Fair
G. P.	Infected sinus tract after reinsertion of tube for spontaneous evacuation of intrapleural blood, 7 days postop.	Fair	Excellent
C. N.	Tube reinsertion for pneumothorax	Fair	Fair

The necessity for re-establishing suction drainage of the pleural space by closed thoracostomy prolonged convalescence only slightly and was effective in obliterating the pleural space in that no patient developed a persistent empyema. Patient D. P., who represents the single poor x-ray result, was lost to follow-up after three months. It is possible that his present status may be much improved.

Technical Considerations.—Though the principle is the same, decortication of tuberculous peel to re-expand the underlying lung differs from the original decortication procedure for inexpansible lung following clotted hemothorax as described by Burford, Parker, and Samson.[2] The partially organized peel of the clotted hemothorax need not be totally excised; only that portion of the visceral pleura overlying the lung is stripped away, freeing the lung for re-expansion. The parietal pleural peel seems largely to resorb within a few weeks once the hemothorax is obliterated. In the case of the tuberculous peel, we are dealing with a much more completely organized, densely fibrous structure, covering both viscera and parietal structures. The peel itself frequently contains large areas of conglomerate caseation, more particularly as

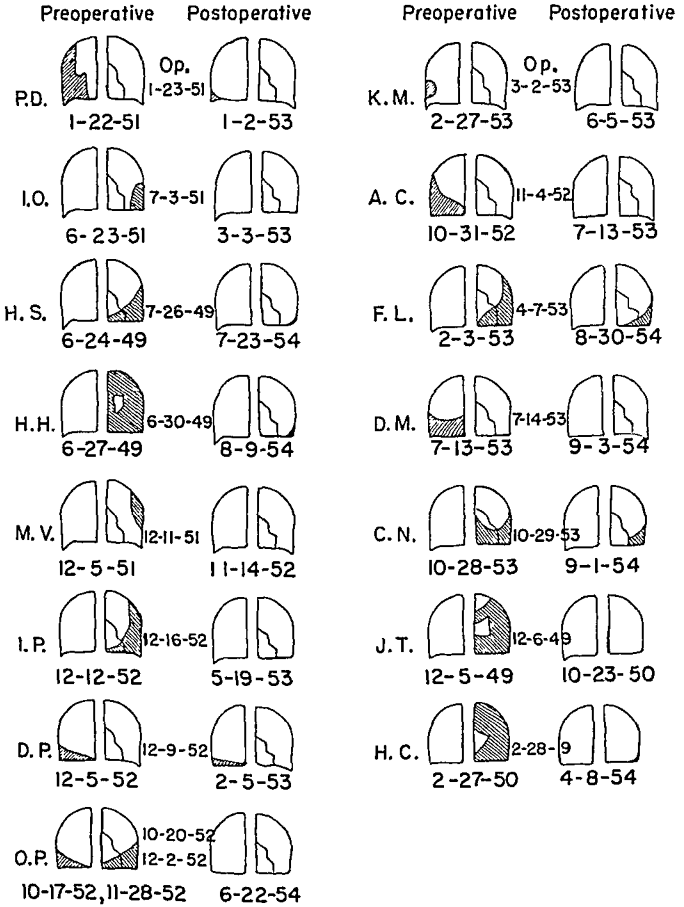

Fig 1.—Composite drawings from preoperative and postoperative x-rays of 15 patients with tuberculous pleuritis

the diaphragm is approached, as if gravity played a part in the more intense tuberculous involvement of the lower thorax. In contrast, the pleural peel covering the mediastinal surface is customarily thin and fortunately strips relatively easily. The ideal (unfortunately not often attained) is a complete excision of the pleural sac intact (see Fig. 2, *A* and *B*). In any case, it is imperative in achieving a good functional result that the parietal and phrenic pleural peel, as well as the visceral peel, be excised. Only in this way can the thorax be freed from its inner dense fibrous stricture allowing the ribs and contracted intercostal spaces to resume their motion. It is our opinion that recovery of function following decortication depends in large measure on the completeness of the excision of the entire peel. In this we are in agreement with Gale,[8] who feels that it is essential to excise the parietal encasement to achieve functional recovery. Tuttle,[16] on the other hand, more concerned with obliterating the empyema space, has followed the original procedure, excising only the visceral peel.

In placing the thoracotomy incision for excision of a complete empyema it is well to follow the area of the sixth or seventh interspaces in order, by low thoracotomy, to allow as ready access to the diaphragm as is consistent with exposure of the thoracic vault as well. Localized collections may demand specially placed incisions, but it is well to remember that the diaphragm is frequently more markedly involved than the preoperative x-rays may make it seem. Dissection of the parietal peel must be carried out through the endothoracic fascial plane. In most cases in which the peel is thick, dense, and fibrous, it is impossible to excise the pleural sac intact. The empyema cavity is entered, evacuated, and an incision made through the visceral peel down to the pleura. It is, surprisingly enough, the rule to find the visceral pleura intact, except in those areas where the presence of a small caseous tubercle may represent the source of the initial inoculation of the pleural space at the inception of the effusion. Gentle, blunt and sharp dissection frees the lung from the peel once a proper line of cleavage is found and maintained. Small tears into superficial lung parenchyma seal readily on later expansion of the lung to meet the parietes. Rapid obliteration of the pleural space and antibiotic therapy combine to prevent the re-formation of a pleural accumulation inoculated with viable tubercle bacilli.

The vascularity of the peel varies with its age and the activity of the inflammatory process. Bleeding tends to be more brisk from the inner surface of the thoracic wall and the diaphragm than from the lung surface. Blood loss is expected to be great and should be measured and replaced volume for volume. In 7 patients, operated upon within six months of their initial effusion, the blood loss averaged 1,500 c.c. Eight patients, with an interval greater than six months, averaged a blood loss of 560 c.c. These figures indicate the peel maturity and well-defined plane of separation in those peels that are more mature and fibrotic.

In certain instances, in which the caseous tuberculosis of the thick, fibrous peel over the diaphragm has made its separation from the superior surface of the diaphragm impossible, we have been forced to excise portions of the diaphragm down to the underlying peritoneum. On the right, the subjacent liver makes this procedure more acceptable than on the left where careful reconstruction of the diaphragm has been necessary to prevent herniation. In any case, we have felt that excision of the caseous tuberculosis of the peel must be complete to prevent re-establishment of the tuberculous empyema. This may be technically taxing.

Re-expansion of the freed lung in the postoperative period may be slow. Air leakage from raw lung parenchyma is inevitable. To aid expansion we have placed tubes at base and apex to which negative pressure has been applied. To counteract marked leakage of air, the Chamberlain pump has been used. Meticulous care that all fluid and air collections are evacuated as rapidly as possible is essential to success.

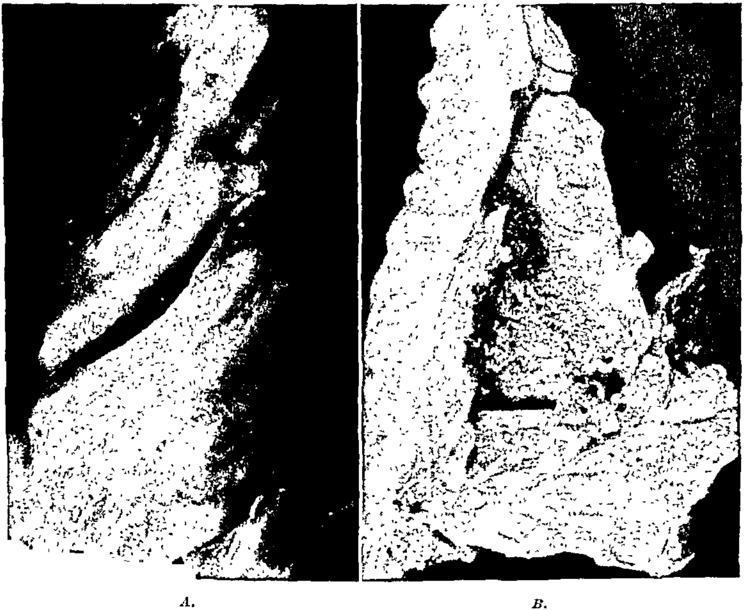
A. *B.*

Fig. 2.—*A*, Parietal "external" surface of 25 by 20 by 4.5 cm. peel. Note rib notching. *B*, Visceral "internal" surface. J. T., 21-year-old woman, operated upon two months following diagnosis of tuberculous pleurisy with effusion. The result was excellent (see Table I). The specimen showed grade 2 *activity of tuberculosis.*

Ten specimens of resected peel were measured and averaged 22 by 17.7 by 4.3 cm., or 1,683 c.c. Except in peels less than six months of age, the size had little bearing on blood loss. Most of the peel specimens were involved in an active tuberculous pleuritis with either caseous nodules, fibrocaseous foci, or simple tubercles of various histologic grades. Eight specimens had definite the diaphragm is approached, as if gravity played a part in the more intense tuberculous involvement of the lower thorax. In contrast, the pleural peel covering the mediastinal surface is customarily thin and fortunately strips relatively easily. The ideal (unfortunately not often attained) is a complete excision of the pleural sac intact (see Fig. 2, *A* and *B*). In any case, it is imperative in achieving a good functional result that the parietal and phrenic pleural peel, as well as the visceral peel, be excised. Only in this way can the thorax be freed from its inner dense fibrous stricture allowing the ribs and contracted intercostal spaces to resume their motion. It is our opinion that recovery of function following decortication depends in large measure on the completeness of the excision of the entire peel. In this we are in agreement with Gale,[8] who feels that it is essential to excise the parietal encasement to achieve functional recovery. Tuttle,[16] on the other hand, more concerned with obliterating the empyema space, has followed the original procedure, excising only the visceral peel.

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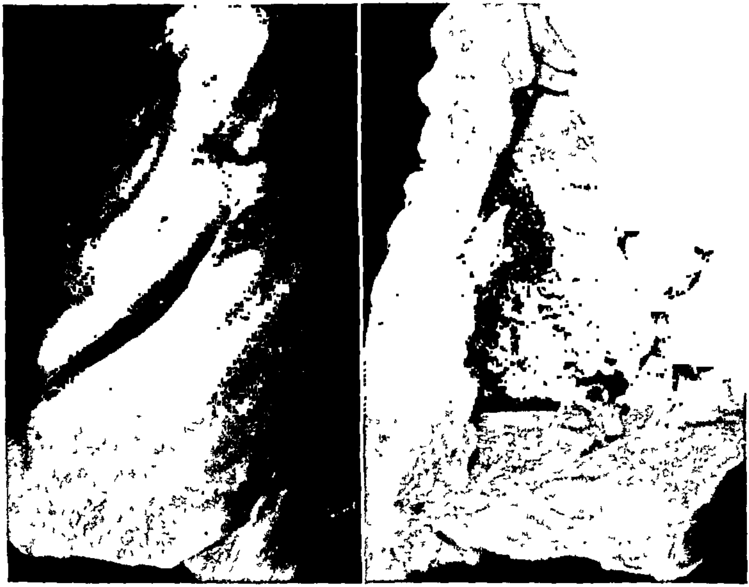

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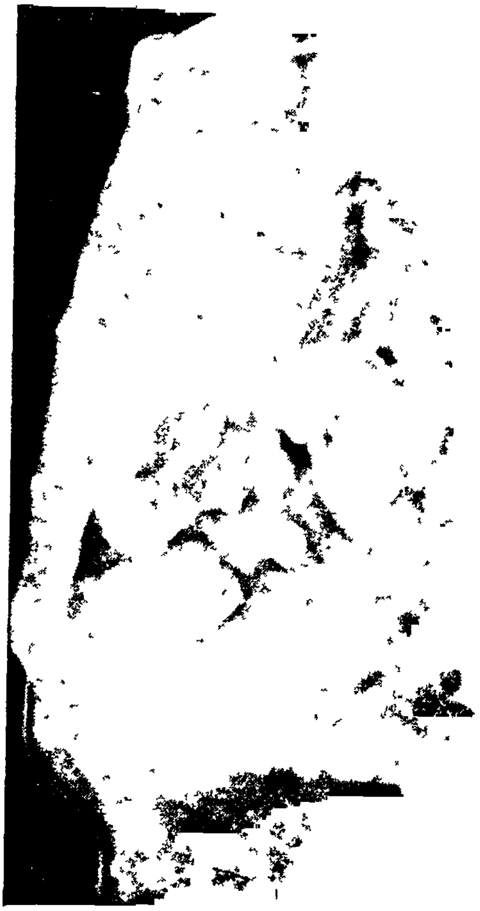

Fig 3—Cross section of caseous nodule 7 by 2 by 1 5 cm K M, 19-year-old girl, operated upon two years and eight months following effusion onset. Classified as "tuberculous empyema," grade 1 plus activity of tuberculosis

Postoperative Function Results.—The literature holds a paucity of pre- and postoperative function studies, particularly bronchospirometric determinations with reference to this problem. Gaensler's work has shown us that bronchospirometric and oxygen uptake determinations are the only accurate method in assessing reduction of lung function since cortication may not change ventilation or reduce vital capacity appreciably.[7] The 4 cases of Falk and his co-workers appear to be the largest series reported.[6] On evaluating their pre- and postoperative figures in the effusion-decortication group, they found that the improvement in oxygen uptake lies in the same range as the inexpansible lung (pneumothorax)—decortication group, namely around 8 to 10 per cent. It was their feeling that results were poorer in tuberculous decortications than in nontuberculous decortications due to the inherent tissue changes of tuberculous pleuropulmonary disease Since the inexpansible lung and posttherapeutic pneumothorax empyema often represent extensive underlying parenchymal disease with a superimposed pleural cortication, we believe the results can not be truly comparable

Carrol, McClement, Himmelstein, and Cournand, reporting postoperative function studies on 3 patients with tuberculous pleural disease treated with decortication, were among the first to show significant improvement in function (oxygen consumption) in those cases with little to no demonstrable parenchymal disease and with pleural disease of short duration[3] Patton, Watson, and Gaensler state clearly that restoration of function after decortication is closely related to the presence or absence of pre existing parenchymal disease[13]

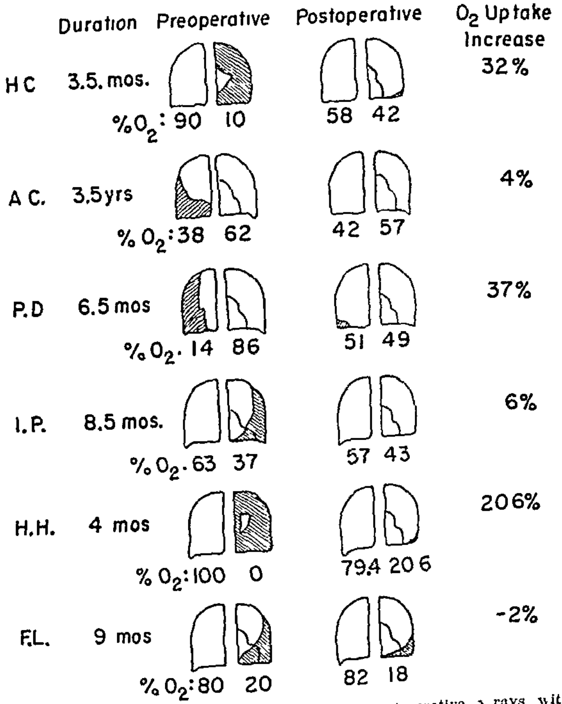

Fig 4—Composite drawings of preoperative and postoperative x rays with bronchospirometric function valves (oxygen uptake per cent) of 6 patients with tuberculous pleuritis

Table II details the total function studies obtained in 6 of the 16 cases reported, and Fig 4 briefly summarizes the correlation of these results wi the x ray findings (schemogram) and duration

TABLE II. PULMONARY FUNCTION STUDIES IN 6 PATIENTS BEFORE AND AFTER DECORTICATION FOR TUBERCULOUS PLEURITIS

	PREOPERATIVE STUDIES								POSTOPERATIVE STUDIES*							
	LUNG FUNCTION				BRONCHOSPIROMETRY				LUNG FUNCTION				BRONCHOSPIROMETRY			
					UPTAKE O_2 PER CENT		VENTILATION O_2 PER CENT						UPTAKE O_2 PER CENT		VENTILATION O_2 PER CENT	
PATIENT	PRE-DICTED MBC	OBS.† MBC	PRE-DICTED PER CENT	VC PER CENT	R	L	R	L	PRE-DICTED MBC	OBS.† MBC	PRE-DICTED PER CENT	VC PER CENT	R	L	R	L
H. C.	135.5	78.7	58.0	55.4	90	10	96	4	140	93	66.0	61	58.0	42.0	53.0	47.0
A. C.	127.0	93.5	73.5	53.0	38	62	42	58	122	96	78.5	54	42.0	57.0	48.5	51.5
P. D.	100.0	76.0	76.0	51.0	14	86	39	61	99	85	86.0	63	51.0	49.0	51.0	49.0
I. P.	96.0	91.0	94.0	86.0	63	37	62	39	97	94	97.0	94	57.0	43.0	54.0	46.0
A. H.	141.0	105.0	74.0	45.0	100	0	100	0	141	135	95.0	60	79.4	20.6	72.0	28.0
F. L.	99.0	76.0	76.5	45.0	80	20	74	26	---	---	---	--	82.0	18.0	76.0	24.0

*All postoperative studies carried out six to seven months following decortication.

†OBS = Observed.

Three of these patients (H. D., P. D., and H. H.) showed striking improvement in oxygen consumption after decortication. The duration of their disease before surgery was less than seven, three and one half, six and one half, and four months, respectively. All, initially, had less than 15 per cent oxygen uptake on the involved side. Of the remaining 3, A. C. and I. P. had excellent x-ray improvement but negligible improvement in oxygen uptake. The preoperative levels of 2 patients, however, were not markedly depressed, being 38 per cent and 37 per cent, respectively. The last patient, F. L., showed gradual improvement over a two-year period in x-ray films but revealed no significant degree of oxygen uptake percentage increase. Severe postoperative hemothorax undoubtedly contributed to his failure to improve functionally. Of all the 6 patients studied in this fashion, those 3 who derived x-ray and function recovery had, by sputa and tomographic study, the least degree of intrinsic pulmonary tuberculous disease. We wish to emphasize the point again that it is in this group of patients that decortication for tuberculous pleural disease will accomplish the most significant degree of functional improvement.

DISCUSSION

Decortication of an active tuberculous peel and empyema is important in the total rehabilitation of patients with unresolved or organized tuberculous pleuritis. Its role is dependent upon the unsuccessful re-expansion of the involved lung or unsuccessful ablation of the constricting peel by other conservative measures. Serous pleural effusions, with or without positive tuberculous organisms, will often be followed by the development of a fibrotic pleural peel, the ideal surgical maturity of which is probably two to four months. Unaspirable fluid with x-ray evidence of residual pleural opacification heralds the build-up of this peel. Disregarding functional disability, slow and protracted improvement in x-rays would be expected. When time and function are important as in this problem, decortication of the peel should be considered. Mixed empyemas, on the other hand, are dependent on the presence of an open bronchopleural fistula. Such fistulas, in our experience, cannot often be closed successfully without resection of the portion of lung from which the fistula originates, which usually demands pleuropneumonectomy. Mixed empyema is therefore, in most instances, a contraindication to an attempt at decortication.

One expects, depending on the size of the peel, reduction in total lung function. We concern ourselves with reduction in oxygen consumption (milliliters of oxygen removed by pulmonary capillary blood flow), believing this to be a more definite criterion of absolute function than the MBC (maximum breathing capacity) and VC (vital capacity) determinations so often performed in these cases. The oxygen uptake or consumption reflects the volume of pulmonary capillary blood flow and the amount of oxygen in the incoming venous blood, the latter generally constant for age, size, etc., if the metabolic rate of tissues for oxygen is not increased. The maximum breathing capacity and vital capacity studies in the presence of almost complete hemipleural obliteration may erroneously show near normal function since ventilation may be maintained. Though the pliancy of lung tissue is reduced by the pleural peel this single factor may be overcompensated by muscular force and rate increase in the presence of a clear and free airway. Despite maintenance of ventilation, circulatory perfusion, as evidenced by oxygen uptake studies, may be markedly reduced. This is accounted for by reduced pulmonary capillary flow, second to increased peripheral resistance, known to occur in compressed lung.[4, 13] Generally, however, both ventilation and perfusion studies are equally reduced with encasement of a lung.

We feel justified by this experience in challenging such statements as "decortication in pulmonary tuberculosis does not offer the degree of improvement in pulmonary function often noted after decortication in nontuberculous disease and should not be the primary object of such therapy in tuberculosis."[18] True, the excision of the empyema is most often the consideration of first importance. But if the effusion which is no longer aspirable is attacked early, gratifying return of function to normal or near normal levels may result.

SUMMARY

1. An analysis of 16 cases of organized tuberculous pleuritis treated by visceroparietal decortication is presented. Of the 16 cases, six preoperative bronchospirometric determinations are included with accent on comparative oxygen uptake studies.

2. Certain technical points are stressed for maximum operative achievement. Parietal pleurectomy to accompany visceral pleural ablation is strongly urged.

3. Decortication as a primary operation for tuberculous pleural disease in the presence of minimal parenchymatous involvement is generally safe and is not associated with appreciable mortality and prolonged morbidity. When bronchospirometric studies of the involved side disclose reduction in oxygen uptake to levels below 15 to 20 per cent and the duration of the disease is short, one can expect return of ventilatory and circulatory function to normal or near normal levels.

We wish to thank Dr. James Martin, head of the Pulmonary Physiology Laboratory at Firland Sanatorium, for his bronchospirometry data used in this report.

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obliteration may erroneously show near normal function since ventilation may be maintained. Though the pliancy of lung tissue is reduced by the pleural peel this single factor may be overcompensated by muscular force and rate increase in the presence of a clear and free airway. Despite maintenance of ventilation, circulatory perfusion, as evidenced by oxygen uptake studies, may be markedly reduced. This is accounted for by reduced pulmonary capillary flow, second to increased peripheral resistance, known to occur in compressed lung.[4, 13] Generally, however, both ventilation and perfusion studies are equally reduced with encasement of a lung.

We feel justified by this experience in challenging such statements as "decortication in pulmonary tuberculosis does not offer the degree of improvement in pulmonary function often noted after decortication in nontuberculous disease and should not be the primary object of such therapy in tuberculosis."[18] True, the excision of the empyema is most often the consideration of first importance. But if the effusion which is no longer aspirable is attacked early, gratifying return of function to normal or near normal levels may result.

SUMMARY

1. An analysis of 16 cases of organized tuberculous pleuritis treated by visceroparietal decortication is presented. Of the 16 cases, six preoperative bronchospirometric determinations are included with accent on comparative oxygen uptake studies.

2. Certain technical points are stressed for maximum operative achievement. Parietal pleurectomy to accompany visceral pleural ablation is strongly urged.

3. Decortication as a primary operation for tuberculous pleural disease in the presence of minimal parenchymatous involvement is generally safe and is not associated with appreciable mortality and prolonged morbidity. When bronchospirometric studies of the involved side disclose reduction in oxygen uptake to levels below 15 to 20 per cent and the duration of the disease is short, one can expect return of ventilatory and circulatory function to normal or near normal levels.

We wish to thank Dr. James Martin, head of the Pulmonary Physiology Laboratory at Firland Sanatorium, for his bronchospirometry data used in this report.

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THE ARTERIAL DISTRIBUTION TO THE LEFT UPPER PULMONARY LOBE

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THE discrepancy noted between our experience with the arterial supply of the left upper lobe and that described in the literature has prompted us to record the patterns which we have encountered. As so frequently happens in medicine, an original misconception, often reiterated, and accepted uncritically attains all the validity of an established fact.

We are particularly concerned with the obviously erroneous conception that the first branch of the left pulmonary artery is an apical or apicoposterior vessel rather than an anterior or apicoanterior trunk. The concept that the lingular artery is very frequently the source of at least a part if not the major arterial supply of the anterior segment is also considered unrealistic.

As nearly as can be determined, Kent and Blades[1] in 1942 made the first attempt to advance the knowledge of the arterial anatomy of this area beyond the meager descriptions of the Gray, Cunningham, and Spalteholz texts. They described the course of the left main pulmonary artery and found that it gave off from 4 to 7 short trunks which supplied the upper lobe.

In 1944, Appleton[2] described the anatomic distribution of the blood vessels as gathered from the study of the dissections of 50 right and 50 left lungs. His description of the left pulmonary artery states, "this artery in arching over the left upper lobe bronchus provides arteries for the apical and posterior bronchi. Now the artery for the pectoral segment bronchus occasionally arises anteriorly before the arch; more often it arises afterwards, and it is then below the origin of the artery of the dorsal segment of the lower lobe. The lingular artery usually arises after the main artery has arched over the bronchus; it then passes forward below the bronchus." The statement referable to the anterior (pectoral segment) artery arising after the posterior artery is definitely incorrect yet has been repeated again and again in subsequent texts by various authors.

In 1945, Boyden[3] wrote on the intrahilar and related segmental anatomy of the lung based on the dissection of two pairs of lungs. He stated, "The first branch of the left pulmonary artery is an apicoposterior trunk (the apical of Herrnheiser and Kubat, or ascendens of Melnikoff). It arises on the convex superior surface of the pulmonary artery and, according to Melnikoff, is most commonly a sessile trunk which divides immediately into apical and posterior segmental arteries." In his figures, Boyden showed the anterior artery arising

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from the lingular trunk and it was so described in the text along with another variation which depicted the anterior artery as a branch from a common anterior apico posterior trunk.

In 1946, Boyden[4] reported a more extensive analysis of the variations in the left upper lobes of 50 lungs. This study is essentially in rather close agreement with our own conclusions. He found that the number of arteries to the upper lobe varied from 4 to 8 with a mean number of 5.4. In only 14 per cent of the cases did he find even part of the anterior segment supply arising from the lingular artery. In only 22 per cent of the specimens did he find a common apicoposterior segmental artery. He stated, "Of special interest is that the apical and posterior vessels arise independently of each other in more than ¾ of specimens notwithstanding the fact that the corresponding bronchi arise in 78 per cent of specimens from a common stem."

Sweet,[5] in his text in 1950, described the left pulmonary artery as follows: "The artery arches upwards, inclining posterolaterally above the bronchus. At this point it usually gives off its first upper lobe branch which is distributed to the apical and posterior segments. . . . The main vessel rises over and curves behind the upper lobe bronchus. Along this curved portion it gives off one or more branches to the apical, posterior and anterior segments." In Fig. 87, page 162, in the illustration of a left upper lobectomy, the first and second branches are separate apical and posterior arteries while the third vessel is the anterior and the fourth is the lingular artery. In contrast, however, Fig. 15, page 32, a colored three dimensional diagram of the left upper lobe segments, depicts the first artery going to the anterior segment, the second to the apical, the third to the posterior, and the fourth to the lingular segment. This latter description is essentially the arrangement we have found.

Overholt and Langer[6] in the revised 1951 edition of their text describe the arteries to the left upper lobe as follows: "We have found them most frequently from four to six in number arising from the pulmonary artery independently as short stems. At other times the segmental arteries have been found to have common trunks. The apico posterior trunk has two branches for the apical posterior bronchus, and the anterolingular trunk has three branches, one for the anterior segmental bronchus and two for the lower division of the left upper lobe branchus (lingula). . . . The anterior segmental artery arises in the interlobar portion of the pulmonary artery as a branch of the anterolingular arterial trunk or independently from the main artery." Notwithstanding the above description, the colored diagram, Fig. 27, page 90, is said to illustrate "the most common arterial pattern." It shows two branches to the upper lobe, the first is an apicoposterior trunk while the second is a large anterolingular trunk. Again, in a description of the technique of left upper lobectomy, page 127, Overholt states that "the apical-posterior arteries are the uppermost branches of the pulmonary artery."

Johnson and Kirby, in their 1952 text, state on page 143, "The first branch, the apical posterior trunk, usually arises just as the main artery begins its posterior inferior curve and subdivides into the apical and posterior segmental arteries. It is not uncommon for the apical and posterior arteries to arise separately. The next branch is the anterior segmental artery which arises most commonly from the anteromedial surface of the main trunk within the fissure. Two variations of the anterior artery are frequently encountered. It may arise as the first branch of the main pulmonary artery anteriorly, in the primary hilum, or from the lingular arteries." Their anatomic plates show the first branch to be an apicoposterior trunk, the second to be to the anterior segment, and the third as the lingular artery. This same pattern is depicted in plates illustrating a left upper lobectomy.

Lindskog and Liebow,[8] in their 1953 text, quote from Boyden's[4] 1946 article.

METHOD OF STUDY

In an attempt to verify our impression, a set of special study sheets were placed in use early in 1952. Each left upper lobectomy or multiple segmental resection of the left upper lobe performed at Herman Kiefer Hospital was charted immediately after surgery as to the distribution of the arteries. As a teaching procedure for the resident staff, each arterial stem was traced to its first major branching and the destination of these branches determined. Those segmental operations were excluded in which calcification and scarring would have rendered hazardous dissection of vessels other than those which required ligation for the proposed operation. No attempt was made to subdivide the individual pulmonary segment or the arteries thereto. While the identification of the secondary and tertiary branches of the segmental arteries is a delight to the anatomist, it has relatively little surgical importance. The subsegmental resection may readily be accomplished by dissection of the subsegmental bronchus following which the accompanying vessels may be ligated as encountered without the necessity of prior identification. The present report is based on 100 cases where the entire arterial supply to the left upper lobe could be clearly identified and traced.

RESULTS OF THE STUDY

From Table I it is evident that in 87 per cent of the cases there will be 3, 4, or 5 arteries with the greatest number of patients having 4 arteries.

TABLE I. NUMBER OF ARTERIAL BRANCHES TO THE LEFT UPPER LOBE

NUMBER OF BRANCHES	NUMBER OF CASES AND PER CENT
2	5
3	31
4	41
5	15
6	7
7	1
	100%
Mean 3.9	

The illustrations are more or less self-explanatory. From Fig. 1 it is quite obvious that the first branch is not an apical, a posterior, or an apicoposterior vessel. In 80 per cent of the cases it is either an anterior, or an apicoanterior branch. Fig. 2 reveals that in less than 10 per cent of the cases does the anterior segment receive more than one artery. Figs. 3, 4, and 5 reveal that the arterial supply to the apicoposterior segments is varied indeed although in over one half of the cases there will be one of four dominant patterns. In the remaining 43 per cent, however, there will be eighteen separate and distinct patterns of vascularization.

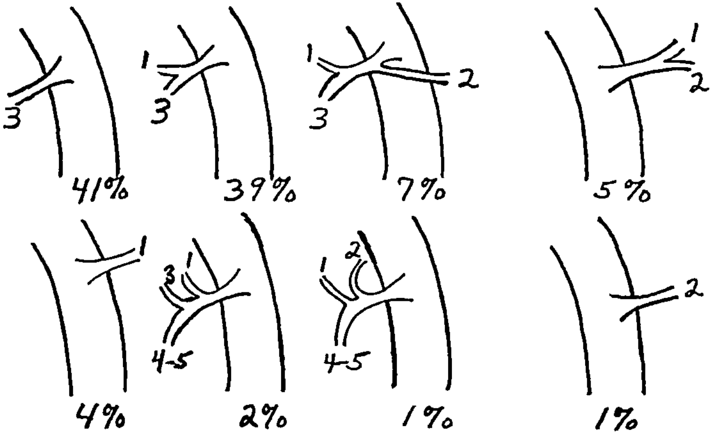

Fig. 1.—The first branch of the left pulmonary artery. In all Figures the Jackson-Huber classification is used with *1*, representing the apical; *2*, the posterior; *3*, the anterior; and *4-5*, the lingular segmental arteries. It will be noted that in 80 per cent of the specimens the first branch is either an anterior or apicoanterior artery. By contrast, in only 10 per cent is the first branch an apical, posterior, or apicoposterior artery.

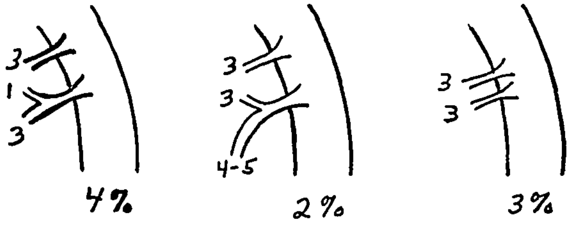

Fig. 2—Multiple arteries to the anterior segment. In 9 per cent of specimens, the anterior segment is supplied by two arteries. In 2 per cent, this auxiliary supply is derived from the lingular artery. Reference to Fig. 7 will show that in a total of 8 per cent *an* anterior artery arises from the lingular branch. Thus in only 8 per cent of the specimens is either the total or partial blood supply to the anterior segment derived from the lingular artery.

Table II. Number of Lingular Arterial Branches

One Artery	89 per cent
Two Arteries	10 per cent
Three Arteries	1 per cent
	100 per cent

Table II illustrates that in the great majority of cases there is a single artery to the lingular segment.

Fig. 6 reveals that in two thirds of the cases, the lingular artery or arteries arise at or below the level of origin of the superior segmental artery. Thus in two thirds of the cases, when performing lower lobectomy, it would be

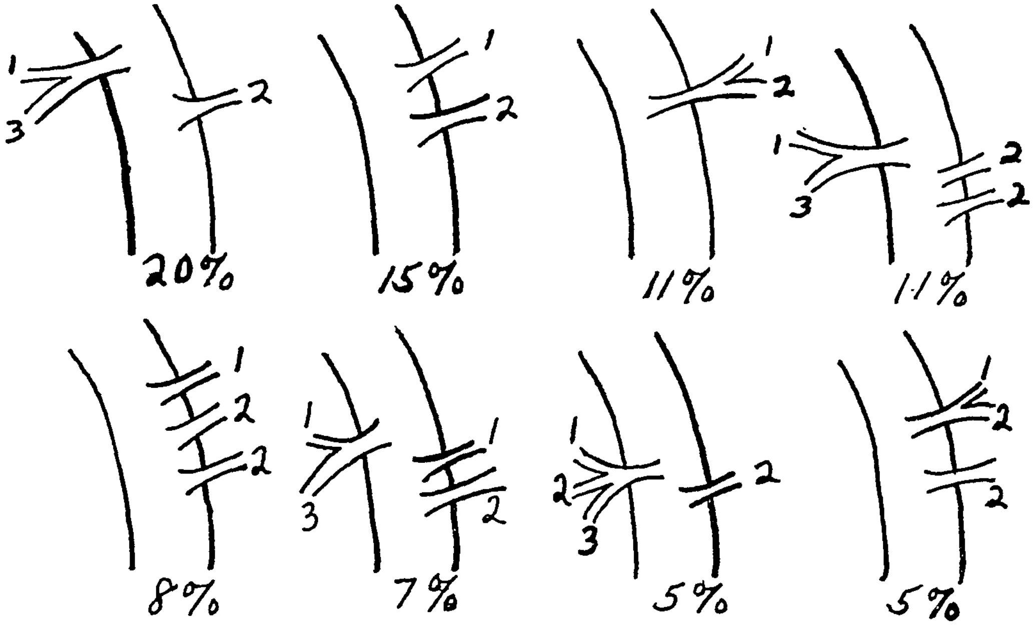

Fig. 3.—The more common arterial distributions to the apicoposterior segments. Well over one half of the specimens will have one of the four distributions shown in the top of the figure. In only 26 per cent (15 per cent + 11 per cent) are these segments supplied solely by a common trunk or by two separate trunks.

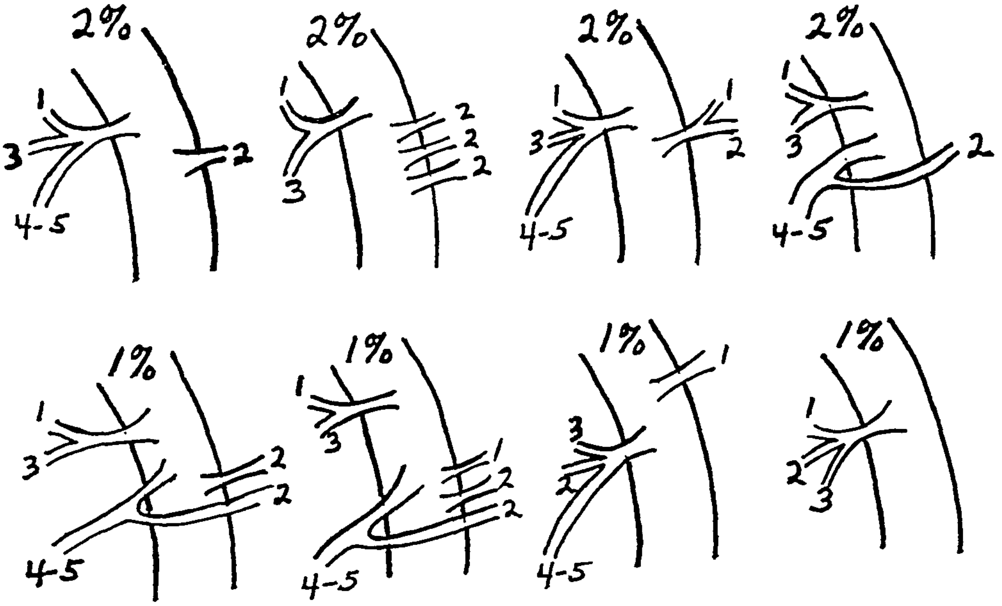

Fig. 4.—Less common arterial distributions to the apicoposterior segments. From Figs. 3, 4, and 5, it is obvious that the vessel pattern to the apicoposterior segments is the most varied of all the segments.

necessary to ligate the superior segmental artery separately and then ligate the main arterial trunk below the origin of the lingular vessels. This, of course, is in agreement with the experience of most observers.

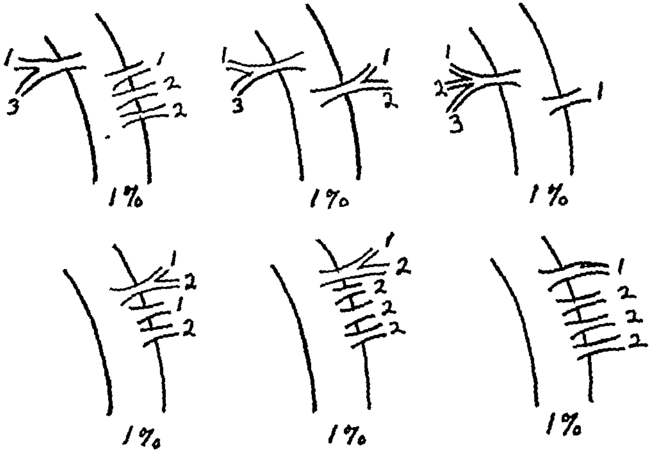

Fig. 5.—Least common arterial distributions to the apicoposterior segments. Reference to Figs. 4 and 5 will reveal that in one fifth of the specimens, fourteen separate and distinct patterns were noted.

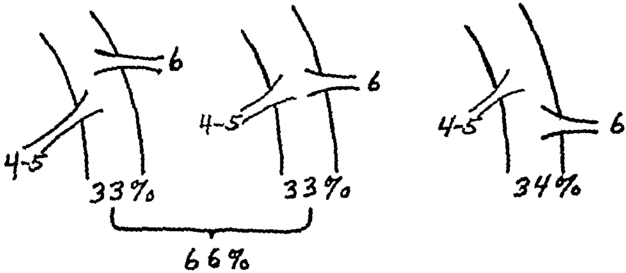

Fig 6—Comparative levels of origin of the lingular and superior segmental (segment 6) arteries. It will be noted that in two thirds of the cases, the lingular artery arises at or below the level of origin of the superior segmental artery. Thus, in only one third of cases, while doing a lower lobectomy, would it be feasible to do a single mass ligation of the arterial supply to the lower lobe.

Fig. 7 demonstrates that in approximately one sixth of the cases only does the lingular artery or arteries supply segments other than the lingula. In only 8 per cent of the cases will the anterior segment receive even part of its supply from the lingular vessels. In 4 per cent the lingular artery sends a branch to one of the basilar segments of the lower lobe. Fig. 8 represents the most common single pattern encountered.

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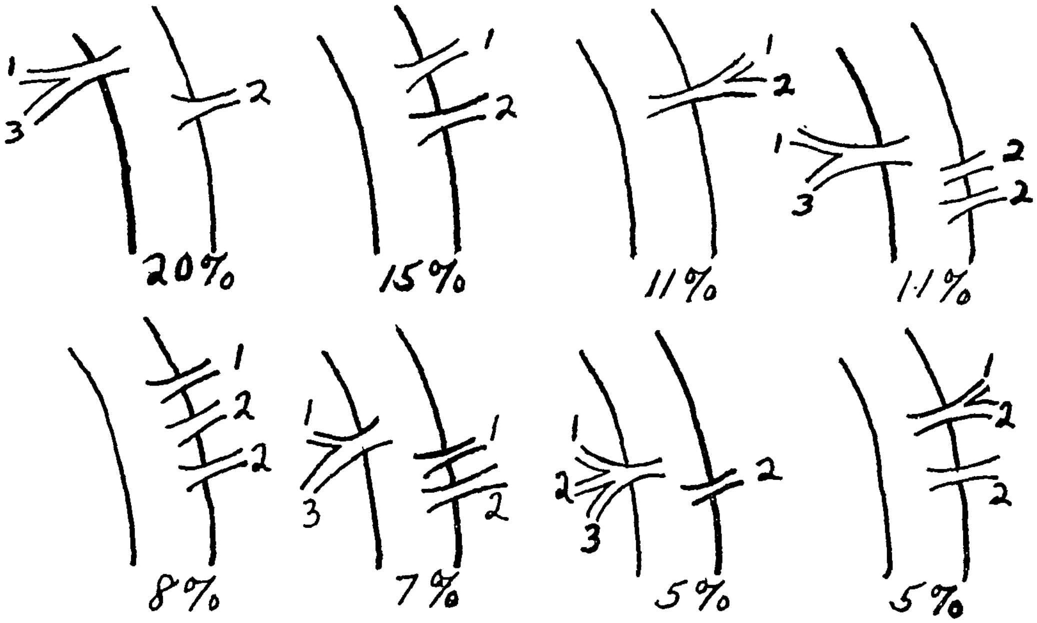

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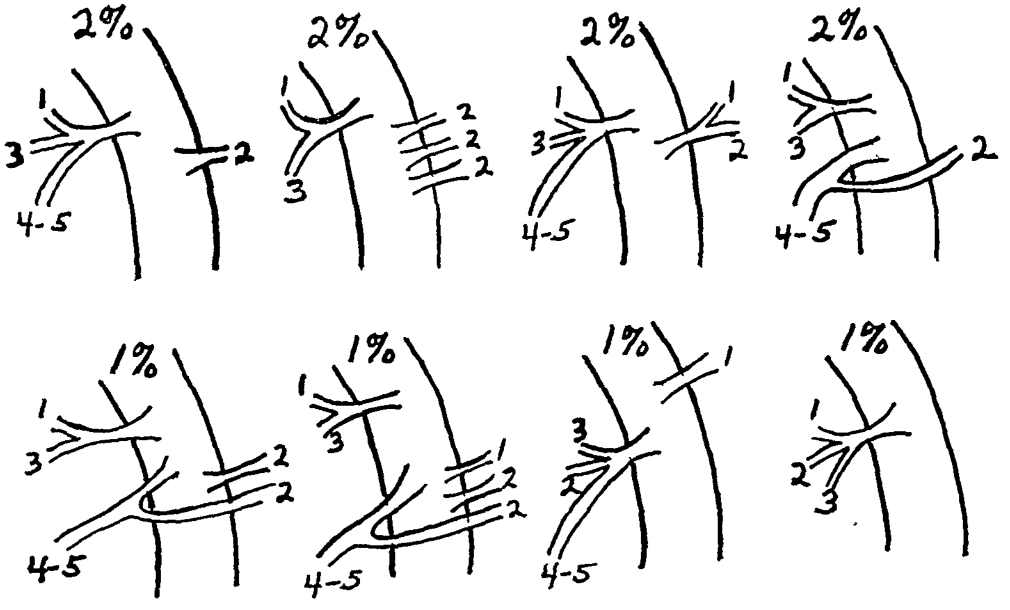

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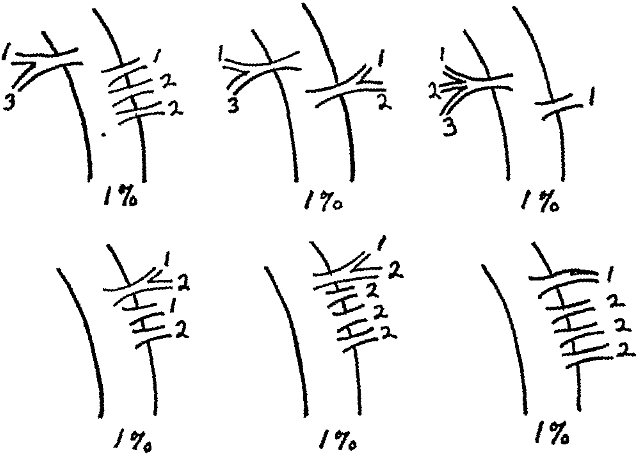
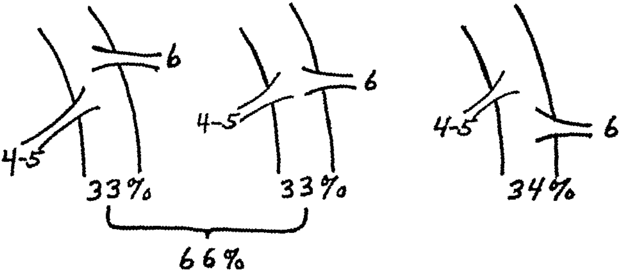


Fig. 5.—Least common arterial distributions to the apicoposterior segments. Reference to Figs. 4 and 5 will reveal that in one fifth of the specimens, fourteen separate and distinct patterns were noted.



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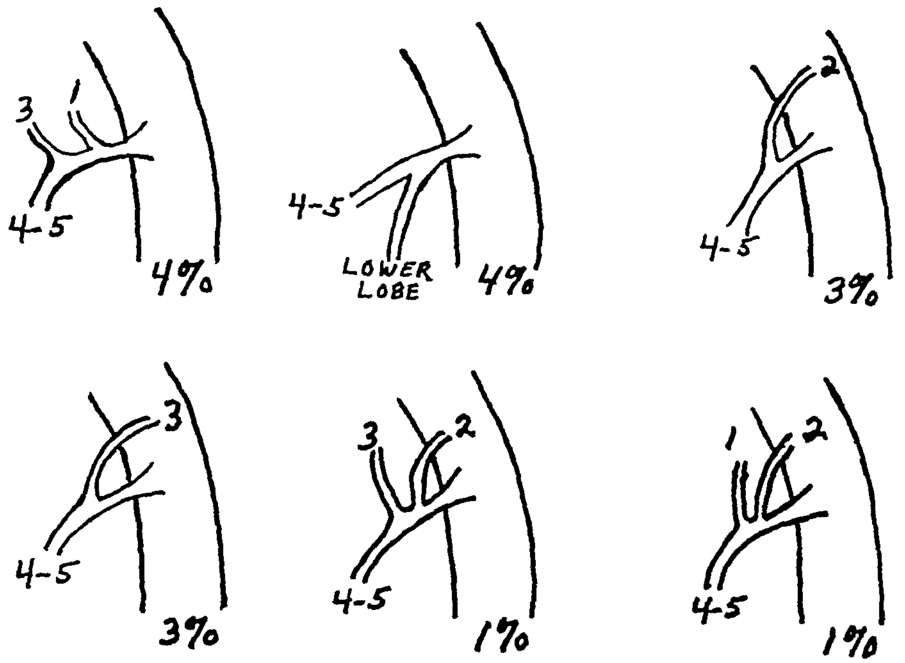

Fig. 7.—Less common lingular artery patterns. Table II has shown the variation in number of the arteries supplying the lingula. This figure shows that in 16 per cent of specimens, the lingular artery or arteries supply segments other than the lingula.

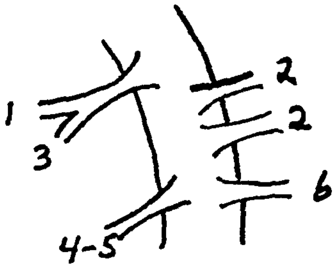

Fig. 8.—*The most common single arterial pattern.*

CONCLUSIONS AND SUMMARY

It has been our purpose in this report to clarify the arterial anatomy of the left upper pulmonary lobe and to correct some misconceptions which have gained wide acceptance through sheer repetition. Whereas it has been stated that the first branch of the left pulmonary artery is most frequently an apicoposterior trunk, we have found in a study of 100 cases that this occurs in only 10 per cent. Conversely, the first branch has been found to be an anterior or apicoanterior artery in fully 80 per cent of the cases. We have not found the lingular artery to be a significant source of supply to the anterior segment. A considerably larger unrecorded experience has shown no major divergence from these findings.

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RECONSTITUTION OF THE LUNG

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THE concept that once the lung has been incised, or a section of tissue has been excised, the remaining raw surfaces cannot or should not be reapproximated, is open to challenge.

Kausel and Lindskog[1] state that most observers have been in agreement with Clagett and Deterling, who are quoted as believing that the raw surface of the lung should not be closed by suture, feeling that such a technique predisposes to obstruction, possible bronchiectasis, and unnecessary loss of lung parenchyma. Reference to the article of Clagett and Deterling[2] does not furnish such a conclusion. Rather, by description and diagram, they illustrate the use of interrupted catgut sutures to approximate the visceral pleura along the line of cleavage (following lingulectomy). Their conclusion being "that as a result of the partial approximation of raw surfaces, the oozing of blood and the danger of poor expansion of pulmonary tissue are further minimized."

The various objections, which have been raised to the reapproximation of raw lung surfaces, may be summarized.

1. There may be some interference with the degree of aeration along the line of resection, where it is particularly vital.
2. Excessive suture material is necessary, which increases foreign body reaction and predisposes to secondary infection.
3. Puckering and reduction in size of the remaining segments are produced: Re-expansion places tension on sutured lung edges, and disruption of the suture level may take place.
4. Over-all re-expansion of the lobe and occupation of residual space in the thorax are prevented.
5. Bronchial distortion is produced, which may result in linear or partial segmental atelectasis and predispose to late bronchiectasis.

The question is proper: Why is any reapproximation of raw lung surfaces necessary? A layer of fibrous and areolar connective tissue (reconstituted pleura?) has been shown both experimentally and clinically to regenerate over raw pulmonary tissue.[1]

Although Chamberlain[3] has concluded that the morbidity following segmental resection is no greater than in lobectomy, several reports[4, 11] in the past five years list an appreciably higher incidence of minor "benign" complications, when comparing segmental resection with lobectomy.

By far, the leading complication has been the persistence of so-called "air leaks." At what point these leaks become bronchopleural fistulas is not clear. We have tried to define a fistula as clinically significant when it requires any

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more than ordinary postoperative care, or unduly prolongs operative convalescence. Thus, prolonged intubation or the necessity of a postresection thoracoplasty would seem to indicate the presence of more than a simple air leak.

The persistence of small bronchopleural fistulas, when segmental resection has been performed for acute or chronic suppurative conditions, is undoubtedly of serious import. The development of local or total empyemas, particularly of the mixed type when the organisms may be drug resistant, constitutes a major problem.

The formation of a postresection space following segmental excision for tuberculosis is, probably, a benign complication when it is considered that the majority of patients who have resection performed today have bacilli which are susceptible to the antituberculous drugs. Thus, inadvertent spillage at operation, or subsequent contamination of the pleural space, is readily controlled. In those patients, however, with resistant organisms known or suspected in the sputum or resected tissues, such ineffective drug control may contribute to local reactivation, empyemas, and fistulas.

When a wedge or triangular shaped defect follows a segmental or deep retrograde wedge resection, the margins of the defect may adhere to the parietal chest wall. Thus, the general pleural space is effectively sealed off, but a pyramidal shaped space is formed. At the apex is the segmental or subsegmental bronchial stump, the two sides are formed by raw lung surface, while the third boundary is parietal pleura. Another variety of such a pseudocavity results when the tip of the superior segment of the lower lobe forms the outer boundary of a space remaining after excision of the posterior or apical posterior segments of the upper lobe. The prompt infection of such spaces by uncontrolled tubercle bacilli has occurred in 8 of our patients when such resistant organisms in the tissues were unsuspected.[5, 6] In one of these cases, fatal hemorrhage followed erosion into a pulmonary vein three months after bisegmental resection. A pseudocavity, such as described previously, with an occult fistula of the apical posterior bronchial stumps was found at post mortem examination.

Judging from the variety of methods which have been suggested for repleuralization, thoracic surgeons have not been unconcerned with the problem of the remaining raw lung surface.

Whenever it is possible for the dissecting fingers to remain in the intersegmental plane, bleeding points and air leaks may be kept to a minimum. The proximity of nodular tuberculosis to the segmental plane, and the desire to encompass such disease by a suitable margin, may cause wedging into the adjacent segment, with subsequent increase in air leakage. Good technique requires the surgeon to arrest any bleeding points or significant air leaks on this raw surface before considering approximation of a pleural flap or any similar sealing maneuver. The use of fine No. 3-0 or 4-0 silk or catgut, applied as interrupted or mattress sutures, is adequate in most instances. Some prefer free ligature about the tip of a mosquito forceps or other fine clamps. These details do not seem important if excess suture material and scattered islands of necrotic debris, or devitalized tissue, are avoided.

Review of current thoracic surgical texts offers no unanimity of suggestions for treatment of the raw lung surface remaining after removal of a segment

Sweet[7] indicates "it *may be left as it is, accepting the greater probability of air leakage;* otherwise, it can be closed by means of continuous fine catgut sutures, which approximate the edges of the lobe, thus pleuralizing the entire surface. A modification of this method is to preserve a long sheet of pleura from the surface of the segment which is being removed as the dissection is carried out. This sheet of pleura is then turned over the denuded area and held in place by sutures around the periphery. There is *reason to believe that the incidence of complications is considerably reduced by closing the denuded surface of the lung.*" Lindskog[8] describes the fashioning of pleural flaps for coverage of bronchial stumps, but indicates no attempt is made to repleuralize the denuded surface. Overholt[9] believes the use of sutures to effect pleuralization following segmental resection has proved to be disadvantageous. "They are difficult to place without inviting air leakage, and the normal shape of the remaining segments is altered and reduced in volume." Scannell[10] describes closure of the wedge-shaped defect, following anterior segmentectomy in the left upper lobe, by approximating the upper surface of the lingula to the apico posterior segment. Incidentally, this maneuver also covered the bronchial stump with normal lung.

Preservation of a suitable flap or apron of visceral pleura may be dangerous, as well as most difficult in segmental resections for tuberculosis, because of the common subpleural location of nodular lesions. Many surgeons have sporadically attempted to reapproximate the cut margins of visceral pleura. Most of these efforts have been doomed to failure, as the apparent dead space in the defect would fill with blood or serosanguineous effusion. In some cases, infection of this operative site with secondary organisms or tubercle bacilli, and evacuation of its contents into the bronchial tree or pleural space, would *result in a pseudocavity larger than that originally present.*

RECONSTITUTION

Because of the frequent observation that lungs with brisk and prolonged air leakage, following segmental or subsegmental resections, were the slowest to re-expand, and were the greatest contributors to the postresection space problem, it appeared that if one raw surface could be carefully approximated to the other, with obliteration of all dead space, primary healing, resulting in a linear parenchymal scar, could be anticipated.

The reapproximation of raw surfaces following unisegmental, bisegmental, or large wedge excision has now been performed in 75 cases. The term reconstitution of the lung has been used, implying the restoration of the lung parenchyma to as near its former continuity and shape as possible.

The technique is described in the accompanying diagrams. Certain points may be stressed.

1. The wedge or pyramidal-shaped defect is closed from the bottom outward (Fig. 1). The same principle is followed as with soft tissue surgery in general; i.e., careful obliteration of all dead space.
2. It is helpful to have the lung partially inflated during reconstitution. A state of atelectasis or full inflation makes suturing difficult and may result in unnecessary deformity.

3. A traction suture at the apex of the defect aids the tendency of the parenchymal surfaces to fall together.

4. The first or crown stitch, at the level of the bronchus, picks up three points; the lowermost limit of the parenchymal pleural margin across to the

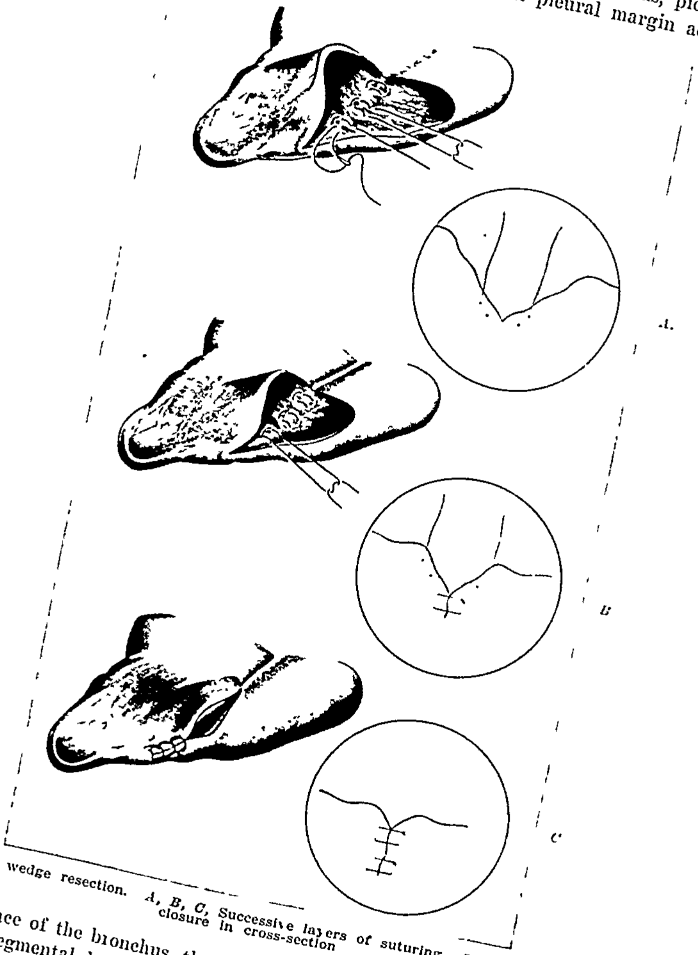

Fig. 1.—Deep wedge resection. *A, B, C,* Successive layers of suturing. Insets Scheme of closure in cross-section

outside surface of the bronchus, then across to the opposite edge. This suture buries the segmental bronchial stump beneath normal lung and completely pleuralizes it (Fig. 2). This detail is stressed in all texts describing segmental resection technique, and we consider it extremely important. The best possible insurance against fistulas of either segmental or lobe bronchus is adjacent lung rising up over the stump and adhering to it.

5. Several sutures are placed as radial horizontal mattress sutures along the base of the defect, at successively more superficial layers, until the margins of the defect are adjacent.

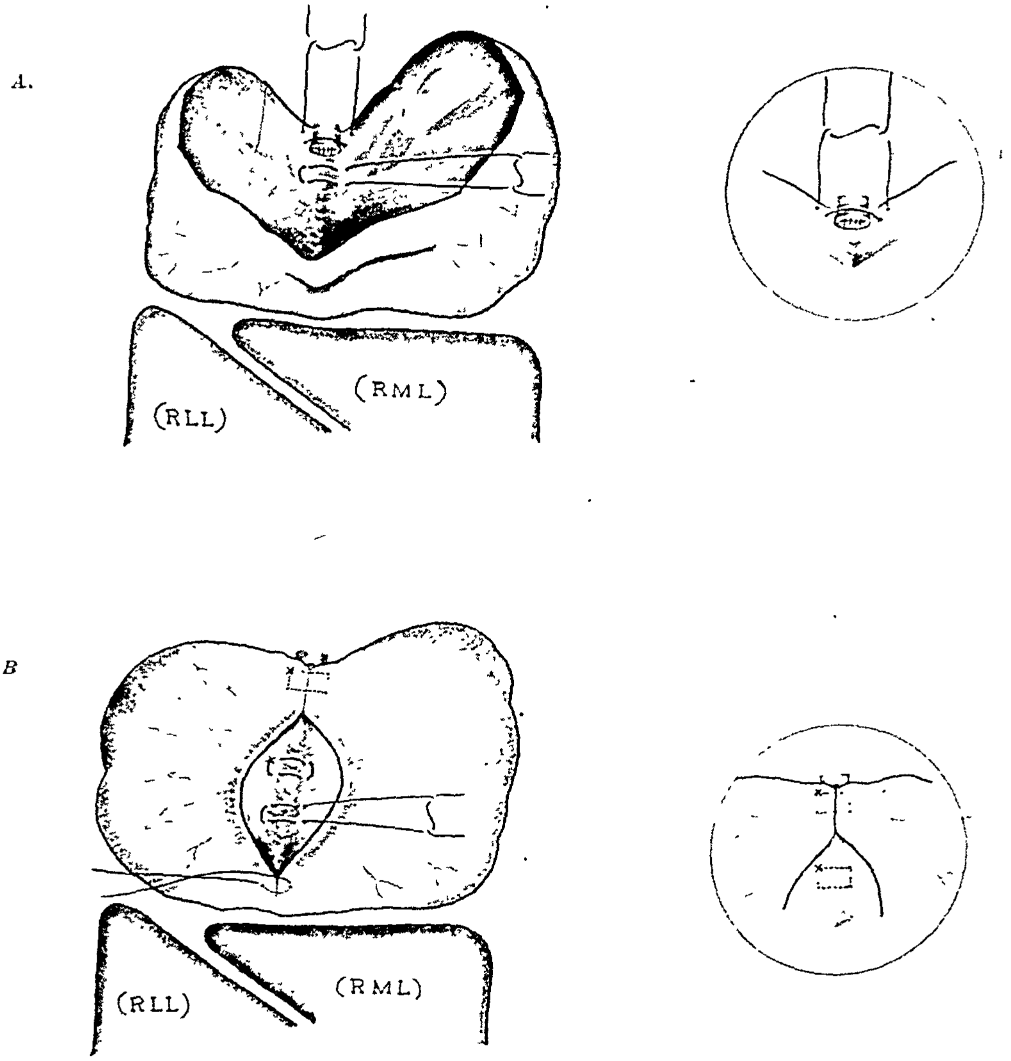

Fig. 2.—Segmental resection (apical). *A*, Beginning of defect closure. Inset: Detail of margin-bronchus-margin suture. *B*, Later stage in closure.

6. It is important that these sutures of either fine catgut or silk, preferably Atraumatic, are placed parallel to the bronchopulmonary ray. This minimizes the chance of transfixing a segmental vein or subsegmental bronchus.

7. If bleeding points and gross air leaks are not controlled before the defect is reconstituted, and further bleeding is caused by poor placement of

sutures, a hematoma may form in the operative site. More likely bleeding will occur into the adjacent lung substance. Several of our earlier cases had distressing hemoptysis for five to seven days postoperatively.

8. Placing a deep suture at right angles to the axis of bronchovascular structures may lead to a complication of this technique. If a particularly large subsegment bronchus is caught in a right angle type suture, an area of parenchyma, distal to this point, may remain unventilated in spite of collateral air drift. This possibility, in addition to any interference with associated blood supply, could result in necrosis and infection of the surgical defect. We have not seen this complication in our material.

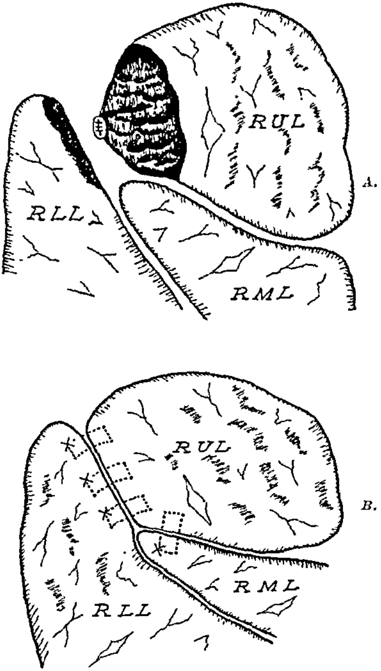

Fig 3.—Alternate method of reconstitution.' *A*, Following posterior segmentectomy. *B*, Use of superior segment, RLL, and medial segment, RML.

SPECIAL SITUATIONS

In addition to the defect following apical or apical-posterior segmental resection in the upper lobe, which lends itself readily to infolding or reapproximation, certain special situations may arise in which th [illegible] of the above techniques are not applicable without causing marked d

Following resection of the posterior segment of the upper lobe, or superior segment of the lower lobe, a somewhat irregular but rather flat surface may result, which has no adjacent raw surface for approximation. Local infolding may succeed in almost complete reconstitution. In the event this is unsatisfactory, the adjacent segment may be approximated to the denuded surface of the upper or lower lobe, respectively (Fig. 3). The medial segment of the middle lobe on the right may join into this triangulation effect. If reconstitution of the left upper lobe is not possible after apical-posterior segmental resection, by bringing the usually overexpanded anterior segment to the superior segment of the lingula, the normally high superior segment of the left lower lobe may easily fall against the defect in the upper lobe.

In most cases where anatomically incomplete fissures are divided, the partial or completely raw surface may be reconstituted and repleuralized by gently rolling in one margin toward the other. In lungs with a fibrotic substrate and moderate emphysematous changes, these maneuvers help significantly to reduce postoperative air leakage and contribute to prompt space occupation.

DISCUSSION

Certain factors, peculiar to tuberculosis, have made the application of lung reconstitution more valuable for segmental resection in this disease than, perhaps, in other pulmonary conditions. It is not usually possible or wise to excise tuberculous lesions, or divide incomplete fissures, with a blind clamping and oversewing technique. The danger of crushing and spilling caseous lesions with the clamps, and then burying this tissue in a continuous locked stitch, is a potential hazard. The only manner in which we have been able to accomplish the removal of all or nearly all palpable lesions in tuberculosis is to "feel our way around the disease." A large nodule may abut on the theoretical segmental plane, and the only way to clear it, and possibly a few satellite nodules, is to wedge slightly into the adjacent segment. This would appear difficult with the use of long Kocher or other crushing clamps.

The widespread location of tuberculous lesions throughout the parenchyma, up to and including the subpleural level, makes the dissection of a pleura flap for purposes of raw surface coverage almost impossible. In addition, the operator runs the ever present danger of breaking into underlying disease during such dissection. The viability of such flaps, either free or pedicled, has always been questionable. At times, the use of parietal pleura, as a so-called apical pleural tent, or fashioned in other ways, has proved useful in covering denuded surfaces.

The common observation that segments adjacent to those containing disease have undergone compensatory overexpansion, while their neighbors contracted, was a point in favor of reconstitution.

Taking advantage of the stage which nature has set, the surgeon can restore the continuity of the parenchyma by approximating the large remaining segments at their raw interfaces. In some instances, the walls of the defects appear almost to fall together, with little or no tension on the suture line. The surgeon may criticize himself for deforming the lung, but the disease has preceded him, and he has only to supplement the body's healing efforts by restoring the continuity of the lung whenever possible.

The further criticism has been raised, whenever reapproximation of segmental defects is advocated, of causing bronchial distortion. Since the bronchi are the most inelastic of parenchymal structures, this objection may be valid. However, the following points should be mentioned. As a result of doing routine Dionosil bronchograms, in the group of open-negative patients (sputum

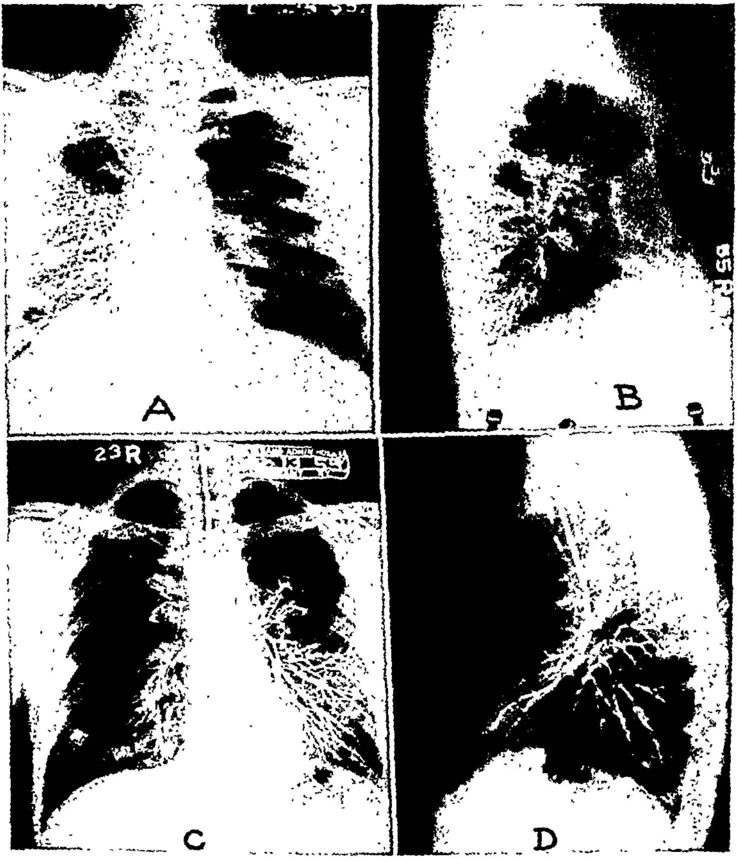

Fig. 4.—*A*, *B*, Bronchogram six months after apical posterior excision, RUL, and reconstitution. *C*, *D*, Bronchogram six months after apical posterior excision, LUL, and reconstitution.

negative for three months and residual annular shadows after six to eight m
of chemotherapy), in order to delineate the nature of these radiolucenc
have found minor degrees of bronchial deformity in the majority. This
true bronchiectasis. At the same time, it is an *anatomic change as*

of disease, which does not appear to result in subjective symptoms. Further, the bronchial distortion which is produced by major and minor collapse procedures, used throughout the years for tuberculosis and demonstrable by random bronchograms, is usually asymptomatic.

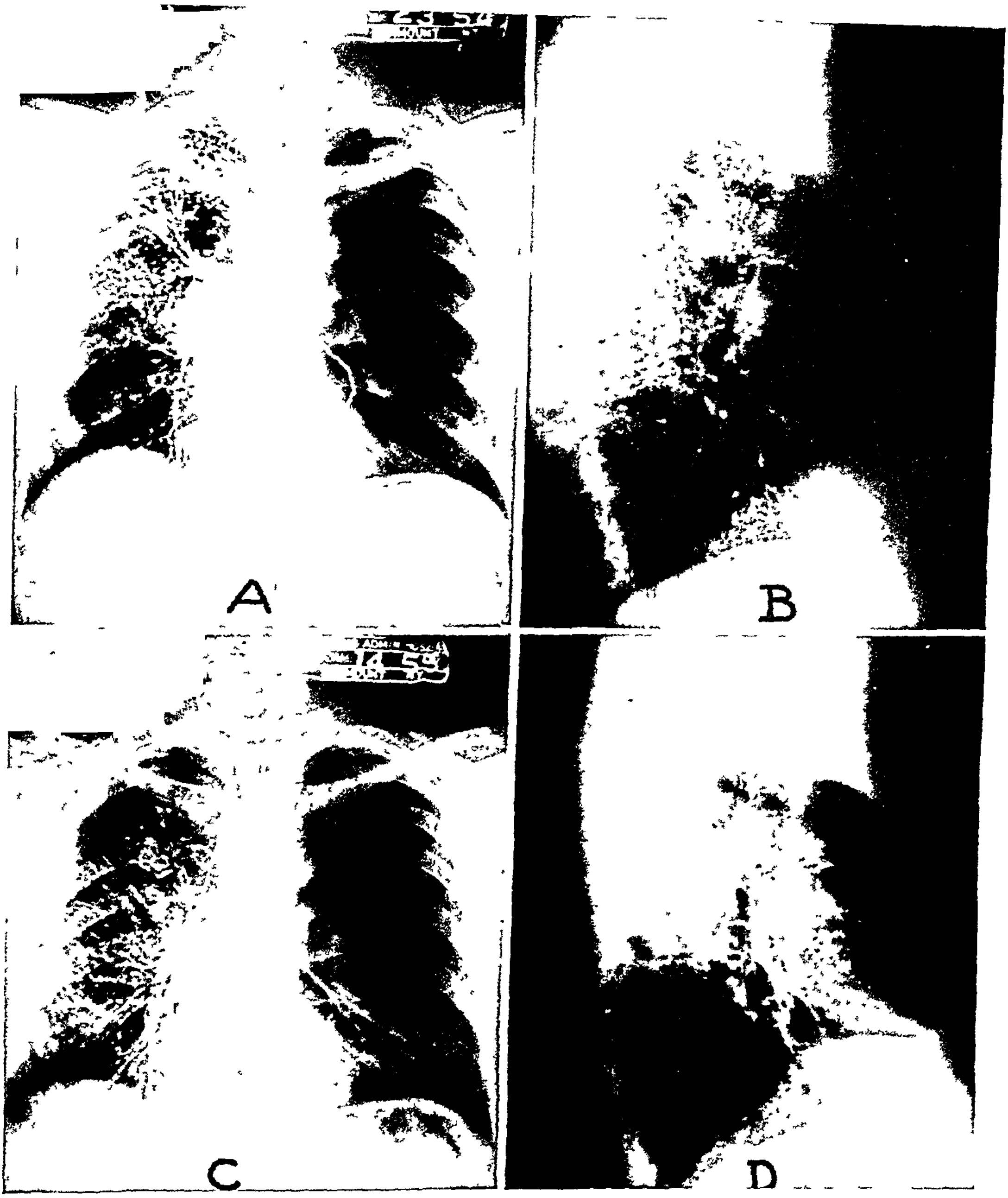

Fig. 5.—*A*, *B*, Bronchogram preoperation. *C*, *D*, Bronchogram five months postoperation, apical posterior segment, RUL, and wedge, superior segment, RLL, with reconstitution.

We are not justifying distortion of the bronchial tree by any surgical procedure, since any appreciable deviation from normal must interfere with bronchopulmonary physiology. However, we wish to recall the probability that a great deal of deformity must exist, either as a result of chronic disease processes or a surgical procedure to treat this disease, that we as physicians are not aware of until the patient's symptoms are sufficient to provoke filling his bronchial tree with contrast media

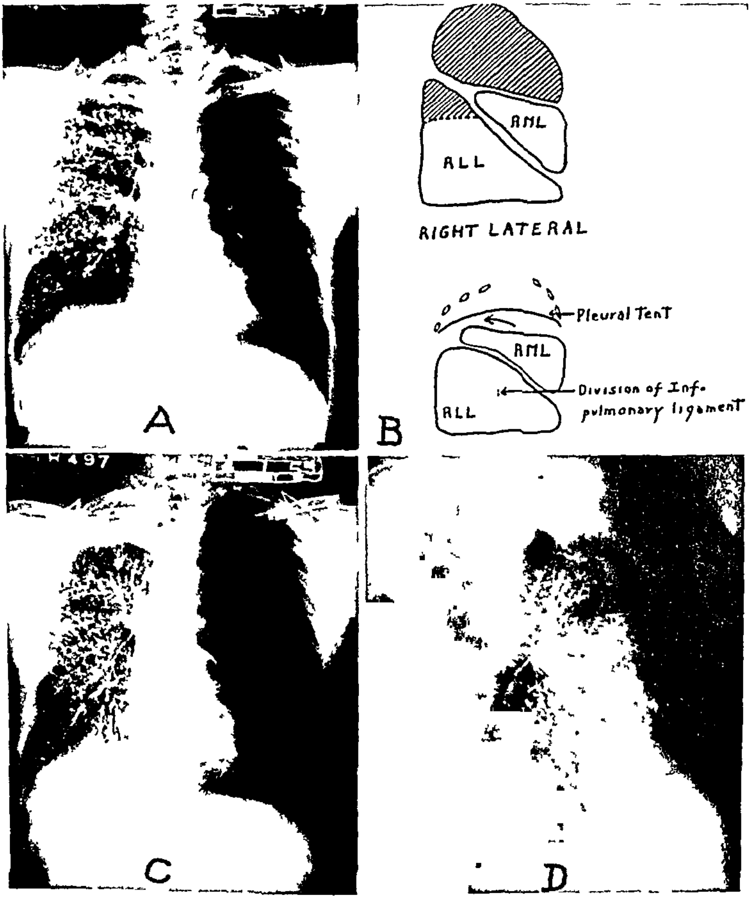

Fig 6 — A Preoperative bronchogram B Diagram of reconstitution after RUL lobectomy and superior segmentectomy RLL C, D Bronchogram six months postoperation

Following reconstitution, we have repeatedly observed prompt inflation of the remaining segments, up to the suture margin, without any evidence of trapping or delay in emptying These findings, plus the absence of any significant deformity in postoperative bronchograms (Figs 4, 5, and 6) st that re constitution in most instances does not contribute to or cause bronchial deformity, at least beyond the ability of the bronchovascular structures to undergo some readjustment.

The benign postoperative course which these patients exhibit is a welcome change to the problem of treating bronchopleural fistulas. Many do not leak air for more than one or two hours, if at all. A former incidence of air leakage and postresection space problems in 20 per cent of our patients, who had segmental resections to October, 1954, has disappeared completely.[11]

SUMMARY

1. The technique of reconstitution of the lung following bisegmental, unisegmental, or deep wedge resection is not presented as an original method. We are sure that varieties of raw surface approximation have been and are being used daily by thoracic surgeons.[4]

2. Our purpose has been to stress the details of the method, as we have used it, with particular application to the problem of segmental resection in tuberculosis.

3. The dangers of allowing a large, triangular-shaped, raw surfaced defect to replace itself in the hemithorax may be significant in a patient with resistant tubercle bacilli in the tissues. The possibilities of formation of an infected pseudocavity or operative defect, bounded entirely by parenchyma or by lung and parietal chest wall, are described.

4. The theoretical objections to reconstitution of the lung are discussed. Practically, the results, both at operation and during the postoperative period, are most satisfactory.*

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CONGENITAL ATRESIA OF THE ESOPHAGUS IN BROTHERS

Herbert Sloan, M D , and Cameron Haight, M D
Ann Arbor, Mich

The discovery of congenital atresia of the esophagus in two brothers has prompted a search for instances of similar esophageal defects occurring more than once in one family The possibility that two children in the same family might be born with atresia of the esophagus has not been seriously considered, since the presumed incidence of esophageal atresia is only one in approximately 3,100 births

In 1880, MacKenzie[1] reported having seen a male infant who died with atresia of the esophagus The infant's father stated that a former wife had given birth to an infant who died nineteen days after birth with the same symptoms as those recorded in the present infant Herzfeld,[2] in 1926, reported the presence of esophageal atresia with tracheoesophageal fistula on autopsy of an infant who was unable to swallow and died six days after birth A sibling, the first child of the same parents, had died forty eight hours after birth with similar symptoms Herzfeld presumed the infants had similar lesions, although an autopsy was not allowed on the sibling

In 1939, Grieve and McDermott[3] reported the occurrence of congenital atresia of the esophagus in two successive male births in the same family The mother and father were third cousins The first boy, born in July, 1937, died shortly after birth and was found to have an esophageal atresia with tracheoesophageal fistula In July, 1938, the mother gave birth to another son with esophageal atresia and tracheoesophageal fistula In addition, this child had an imperforate anus The second child died six days after birth No operation was attempted for either infant

Lanman,[4] in 1940, reported the occurrence of congenital atresia of the esophagus with tracheoesophageal fistula in two successive births in the same family The first patient, a boy, was admitted Dec 2, 1932, at the age of seven hours because of an imperforate anus As the blind end was too high to reach from a perineal incision, a sigmoidostomy was done on December third On the following day, roentgen studies showed complete obstruction of the upper segment of the esophagus and a large amount of gas in the stomach and intestines On exposure of the posterior mediastinum, an esophageal atresia with tracheoesophageal fistula was found, but the patient died on the table In December, 1933, the next child, a girl, of the same parents was admitted at the age of two days with an esophageal atresia with tracheoesophageal fistula At operation the fistula was doubly ligated and divided between the ligatures The lower

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segment of the esophagus was brought out through the wound, a catheter was inserted and the esophagus was sutured to the skin. The patient died eight hours after operation. An autopsy was not obtained in either case.

Copleman, Cannata, and London[5] reported the occurrence of congenital atresia of the esophagus in two successive male siblings. The first patient, born in September, 1946, was found at operation to have an atresia of the upper segment of the esophagus. The lower esophagus was observed to pursue a normal course through the diaphragm. The patient did not survive the attempt at surgical correction. The next infant, born to the same parents in November, 1947, had a congenital atresia of the esophagus, but gas was not observed in the stomach and intestines. A small amount of Lipiodol injected into the upper esophagus resulted in a bronchogram in the subsequent films. The patient died of peritonitis following the establishment of a gastrostomy. At autopsy, a fistula was found between the upper segment of the esophagus and the trachea at about the level of the tracheal bifurcation. The lower segment of the esophagus extended upward for about one inch and terminated in a fibrous cord. The mother gave birth to an apparently normal girl fourteen months later.

Pilcher[6] in a personal communication related two unreported cases of esophageal atresia. The first infant, a girl weighing 3 pounds, 12 ounces, was born on May 18, 1947, and was the first child of her 22-year-old mother. Labor had been induced at eight months because of a complicating hydramnios. The infant regurgitated all feedings and the diagnosis of an esophageal atresia was established when a catheter could not be passed into the stomach. The anus was more anterior than normal and a catheter could be introduced only 4 cm. into the rectum before meeting an obstruction. This finding, coupled with marked abdominal distention, made probable the additional presence of atresia of the colon. For these reasons it was decided not to undertake any surgical therapy. However, three days after birth, meconium was passed and plans were made to treat the esophageal atresia. Accordingly, a right transpleural thoracotomy was performed.

The proximal pouch of the esophagus lay in the thoracic inlet and the distal end of the esophagus reached the hilum of the lung. Because an end-to-end anastomosis of the esophagus could not be accomplished without excessive tension, the stomach was mobilized through the esophageal hiatus and an anastomosis of the stomach to the upper esophageal segment was made with a single layer of interrupted sutures of silk. Four ounces of clear, watery fluid escaped from the stomach when it was opened. The child did very poorly during the operation and several times was believed to have died. At the end of the operation her condition had improved slightly. Death occurred two hours later. An autopsy was not carried out. The large amount of clear fluid in the stomach, which did not contain bile, made probable an atresia of the upper portion of the gastrointestinal tract proximal to the bile duct.

Pilcher's second patient was born to the same mother on Sept. 22, 1948, there having been no intervening pregnancy. The patient was also a girl and weighed 7 pounds, 7 ounces. Normal delivery followed a full-term pregnancy.

A diagnosis of esophageal atresia with tracheoesophageal fistula was made thirty six hours after delivery Two days following birth, operation was performed through a right parascapular incision The distal segment of the esophagus was well developed and entered the trachea above the carina The tracheoesophageal fistula was divided and the fistula was closed with a single layer of interrupted silk sutures The proximal segment of the esophagus overlapped the distal segment so that an anastomosis could be carried out without tension The chest was closed without drainage Feedings by mouth were started two days following operation Ten days after operation the child was taking a full formula and breast feedings were begun on the following day One month after operation, a barium swallow showed normal passage of the material through the esophagus The child was discharged three days later

Dorner[7] in a personal communication related two unreported cases of esophageal atresia in brothers The first infant, who weighed 7 pounds and 4 ounces, was born on May 8, 1949 The mother had been treated for syphilis in December, 1947, but her serologic test for syphilis had become negative The infant was admitted to the hospital three days following birth when he regurgitated feedings A barium swallow showed esophageal atresia An excessive amount of air was present in the stomach and intestines The infant was deeply jaundiced and his temperature was 105 6° F by rectum In the four hours following admission, fluids were administered and the infant was given penicillin, dihydrostreptomycin vitamins C and K, and a small transfusion of whole blood Closure of the tracheoesophageal fistula and an end to end anastomosis of the esophagus were then carried out under local anesthesia The infant did poorly during a part of the operation, but was resuscitated after an endotracheal tube was introduced and respirations were assisted Although the condition of the infant was satisfactory upon completion of the operation, he suddenly became cyanotic ten hours later and could not be resuscitated At autopsy the suture line was intact There was an extensive and overwhelming bronchopneumonia

The second child of the mother of Dorner's patient was a normal daughter Her next child was a boy born on March 5, 1953 The infant regurgitated all feedings and was admitted to the hospital the day after birth He weighed 7 pounds and was in good condition Roentgenograms showed a blind upper esophageal pouch and air in the intestinal tract On the morning following admission, when the infant was two days old, closure of the tracheoesophageal fistula and an end to end anastomosis of the esophagus were carried out under inhalation anesthesia An extrapleural approach was used and, although a tear had been made in the pleura, the lung was expanded easily as the chest was closed A No 8 Fr catheter was placed in the extrapleural space as a drain through a stab wound The infant withstood the operation well On the day following operation, however, he developed a right pneumothorax which was decompressed by means of an anterior intercostal tube On the
following operation, it was necessary to insert a posterior tube
evacuate fluid from the right chest *Pseudomonas aeruginosa* was cu
this fluid A gastrostomy was done at this time for feeding purpose

fant developed a leak at the site of anastomosis and apparently the tracheal closure had also broken down. The infant died on the ninth day following operation. An autopsy was not permitted.

No other examples of esophageal atresia in siblings have been found in the literature, although Morse,[8] in 1920, reported the presence of esophageal stricture in brothers, and Ealing,[9] in 1940, mentioned the occurrence of esophageal atresia in cousins. In only one of the cousins, reported by Ealing, was the lesion confirmed by autopsy.

CASE REPORTS

CASE 1.—D. P., No. 665686, a 3-day-old white male infant, was admitted to the Pediatrics Service of the University Hospital on Nov. 18, 1949. His 24-year-old mother had had a normal pregnancy and delivery. The birth weight was 5 pounds, 14 ounces. The child regurgitated all feedings following delivery. A diagnosis of esophageal atresia with tracheoesophageal fistula was made by the referring physician when roentgenograms taken after an Iodochlorol swallow demonstrated esophageal obstruction at the level of the second thoracic vertebra and the presence of air in the intestines. The only other pregnancy of the mother, three years earlier, was complicated by toxemia and had resulted in a spontaneous abortion. The child's father, paternal grandfather, and paternal great-grandfather were said to have had congenital heart disease.

On examination the infant was a well-developed boy who was slightly dehydrated. His weight was 5 pounds, 7 ounces; temperature 100° F. by rectum. His color and cry were good. Respirations were quiet and dry, and the lungs were clear to percussion and on auscultation. The heart was normal. No other abnormalities were found. The laboratory findings were not remarkable.

Roentgenograms: An Iodochlorol swallow performed before admission demonstrated esophageal atresia with a dilated proximal segment, the lower limit of which lay at the level of the second thoracic vertebra (Fig. 1, *A*). The lungs were clear. Air was present in the stomach and gastrointestinal tract.

Operation: On Nov. 19, 1949, four days following birth, after hydration had been accomplished, an infusion of blood was started in an ankle vein. A right parascapular incision was made and the posterior segments of the third, fourth, and fifth ribs were resected. The mediastinum was explored through an extrapleural approach. The proximal segment of the esophagus was found to bulge inferiorly to the level of the third rib posteriorly. The distal segment of the esophagus entered the trachea at its bifurcation. The distal segment measured 6 to 7 mm. in diameter and was larger than usual. The distance between the proximal and the distal segments measured 9 mm. The distal segment was divided 2 mm. from the trachea, and the opening in the trachea was closed in two layers with a continuous running suture of No. 6-0 silk on an Atraumatic needle. After the proximal segment had been mobilized, an incision 1 cm. in length was made in its tip. A two-layer telescopic anastomosis between the proximal and distal segments was carried out over a No. 8 Fr. catheter, using interrupted sutures of No. 6-0 silk. The proximal segment of the esophagus was tacked to the prevertebral fascia with a few interrupted sutures. The catheter was removed through the mouth. After irrigation of the extrapleural space and the instillation of a small amount of penicillin solution, a rubber wick was placed in the extrapleural space and brought out through the wound, and the extracostal muscles and subcutaneous tissues were closed in layers with interrupted sutures of No. 4-0 catgut. The skin was closed with No. 4-0 silk. The child withstood the procedure well.

Postoperative course: The child's condition remained good. On the second postoperative day, a gastrostomy was carried out for feeding. Fluid balance was maintained with intravenous infusions of 10 per cent glucose solution and subcutaneous infusions of 2.5 per cent glucose solution until full gastrostomy feedings were tolerated. The infant was given dihydrostreptomycin intramuscularly, 50 mg. three times each day, and penicillin intramuscularly, 200,000 units each day. One the fourth day following operation, the rubber wick in the wound was completely removed after it had been shortened on preceding days. The wound healed well. Thirteen days following operation the child was allowed to swallow Iodochlorol. There was 50 per cent constriction of the esophagus at the site of the anastomosis, but no interference with the passage of the oil and no extravasation of the oil into the mediastinum. Seventeen days after operation, oral feedings were begun and the patient was able in six days to maintain his nutrition by oral feedings alone.

The infant was discharged Dec. 24, 1949, on a full diet by mouth. He weighed 6 pounds, 14 ounces. Following discharge he continued to gain steadily. The gastrostomy tube was removed elsewhere on June 7, 1950, and the gastrostomy closed spontaneously. The patient was readmitted on Sept. 28, 1951, with acute pharyngitis and tonsillitis. There had been some difficulty in swallowing during the attack. The child recovered and was discharged weighing 24½ pounds. A Rugar swallow at this time showed no evidence of narrowing of the esophagus (Fig. 1, *B*).

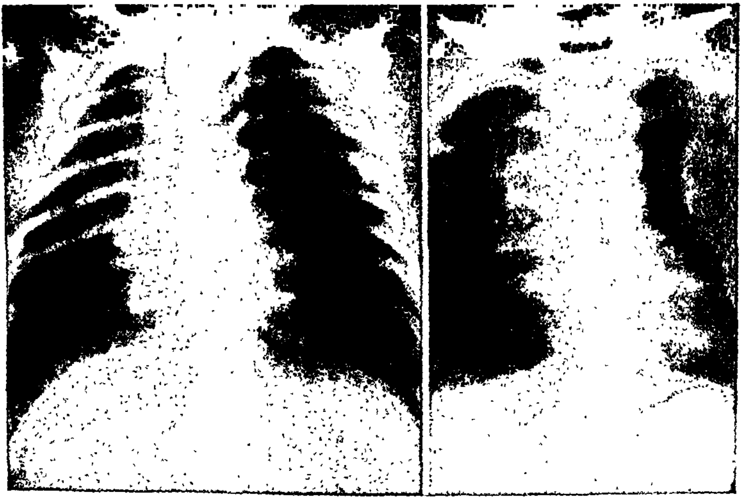
A. *B.*

Fig. 1.—Case 1. D. P. *A*, An Iodochlorol swallow obtained Nov. 18, 1949, three days after birth, demonstrates a blind upper esophageal pouch. There is air in the stomach. *B*, A Rugar swallow obtained Oct 1, 1951. The esophagus is normal and there is no evidence of narrowing.

CASE 2.—T. P., No. 692857, the brother of the previous patient, was admitted to the Pediatrics Service of the University Hospital approximately five hours after birth on Nov. 1, 1950. The infant's physician had not been in attendance at the birth of the first patient, although he had been advised of the findings. The newborn infant was offered glucose solution which was regurgitated and the diagnosis was thereby suspected almost immediately after birth. The pregnancy had been normal and the delivery uncomplicated.

On examination, the infant appeared healthy and in no respiratory dist [illegible] His w [illegible]
was 5 pounds, 11½ ounces; temperature, 97.8° F. by rectum; respirations [illegible]
Mucus drained from the mouth. The lung fields were dry and were clear [illegible]
auscultation. The heart was normal. The remainder of the physical [illegible]
tive. The laboratory findings were not remarkable, alt [illegible] the [illegible]
and the red blood cells 5.4 million.

Roentgenograms: Fluoroscopy and spot films on admission, following the injection of Iodochlorol through a catheter, demonstrated atresia of the esophagus with dilatation of the upper segment, the lower limit of which was at the level of the third thoracic vertebra. A roentgenogram on the following day showed atelectasis of the right upper lobe. Air was present in the gastrointestinal tract (Fig. 2, *A*).

Operation: On Nov. 3, 1950, two days after birth, the mediastinum was explored through a right extrapleural approach following resection of posterior segments of the third, fourth, and fifth ribs. The distal segment of the esophagus entered the trachea just proximal to the carina. The proximal segment of the esophagus lay 1 cm. above the distal segment. The fistula was divided, leaving a 2 mm. cuff of esophageal tissue on the trachea.

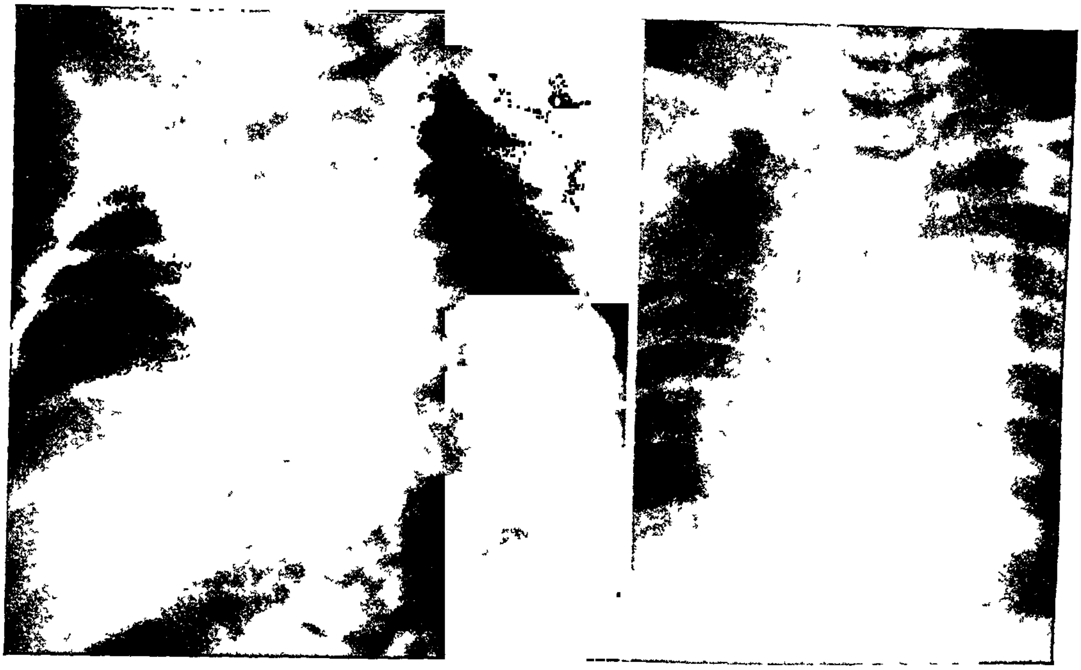
A. *B.*

Fig. 2.—Case 2. T. P. *A*, Preoperative chest roentgenogram obtained Nov. 3, 1950. There is atelectasis of the right upper lobe. Air is present in the stomach.

B, An Iodochlorol swallow obtained April 2, 1951, demonstrates the esophagus lying to the right of the midline. There is slight narrowing of the esophagus at the level of the third thoracic vertebra. The Iodochlorol passes into the stomach without hesitation.

The fistula was then closed in two layers with a running suture of No. 6-0 silk on an Atraumatic needle. A tab of mediastinal tissue was tacked over this with a few interrupted sutures of No. 6 0 silk. The upper segment of the esophagus was freed and an incision 5 mm. in length was made in its tip. A No. 8 Fr. catheter was threaded through both proximal and distal segments and emerged through the mouth. An end to end anastomosis in two layers was carried out with interrupted sutures of No. 5-0 silk, the proximal segment being telescoped over the distal segment by the second layer. There was some difficulty in placing the posterior layers of the anastomosis and there was tension on the suture lines. The catheter was removed through the mouth.

The extrapleural space was irrigated with saline solution and a small amount of penicillin solution was placed in it. The inner end of a rubber wick was placed near the suture line and the wound was closed in layers around the drain with interrupted sutures of Nos. 4-0 and 5-0 silk. Prior to the closure of the wound, it was noticed that the atelectasis of the right upper lobe had cleared. The blood loss was calculated to have been 60 c.c. The infant received 85 c.c. of whole blood through an infusion in the saphenous vein. He withstood the operation well.

Postoperative course In the immediate postoperative period the infant's condition continued to be good He received intramuscularly 50 mg of streptomycin four times each day, and 200,000 units of penicillin each day Fluid balance was maintained with intravenous infusions of 10 per cent glucose solution and subcutaneous infusions of 5 per cent glucose solution On the third day following operation the infant was allowed to swallow *Iodochlorol Roentgenograms showed the esophagus to be patent and there was no extravasation* of the oil Oral feedings were started on the following day At this time removal of the rubber drainage wick was completed On the ninth postoperative day, a small portion of the feedings was noted to have escaped through the posterior wound Roentgenograms following an Iodochlorol swallow on the following day showed extravasation of the oil into the mediastinum For this reason a gastrostomy was done for feeding Drainage through the posterior wound gradually ceased and oral feedings were resumed on Nov 27, 1950, after an Iodochlorol swallow showed a patent esophagus and no extravasation of the oil

The infant was discharged on Dec 6, 1950, weighing 6 pounds, 4¾ ounces He continued to do well and his weight gain was steady The gastrostomy tube was removed five months after operation Examination of the esophagus at this time showed some *narrowing but no delay in emptying of the esophagus (Fig 2, B) The infant* was last seen on June 4, 1951, when he weighed 15 pounds, 15 ounces, and was taking a normal diet The parents have now moved to another state and re examination has not been possible A report, however, indicates that this patient and his brother are progressing well

DISCUSSION

Esophageal atresia with or without tracheoesophageal fistula in children of the same parents has rarely been described It had been felt that the possibility of this abnormality occurring more than once in siblings was almost nonexistent The presence of esophageal atresia, however, has been confirmed in six pairs of siblings and suspected in two additional pairs In the series of cases of atresia of the esophagus at the University of Michigan Hospital the anomaly has occurred in siblings only once in 182 families

SUMMARY

1 Two brothers, born successively, were found to have esophageal atresia with tracheoesophageal fistula Successful repair of the anomaly was carried out in both infants

2 The known cases of verified or presumed esophageal atresia in siblings are reviewed Since the presence of esophageal atresia in siblings has been verified only six times and suspected in two other instances, the probability of its occurrence more than once in a family seems remote

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EARLY COMPLICATIONS FOLLOWING RESECTION FOR PULMONARY TUBERCULOSIS

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ACCUMULATED evidence shows that resection for pulmonary tuberculosis can be performed with a very low operative mortality.[*] However, the incidence of complications has not decreased to a corresponding extent. For this reason it seems important to review the more serious complications (Table I), which occurred following 355 consecutive pulmonary resections for tuberculosis performed at the Ray Brook State Tuberculosis Hospital between Jan. 1, 1950, and July 1, 1955, in the hope of discovering not only their causes, but also the most effective method of preventing and treating them. Residual air-containing pleural spaces, although no longer a serious problem, are also included in this study.

TABLE I

COMPLICATIONS		NUMBER
Operative spread of disease		3
Hemothorax		7
Atelectasis		1
Major wound sepsis		5
Bronchopleural fistula and empyema		20
a. with tuberculous empyema	7	
b. with probable tuberculous empyema	4	
c. with nontuberculous empyema	2	
d. without empyema	7	
Infected emphysematous bulla		1
Total		37

Three deaths due to pulmonary edema, cardiac arrest, and cause undetermined are not considered within the scope of the study.

Since some of the morbidity is due to tuberculous infection, it is of interest to note that 88 of 355 resections were performed upon patients with positive sputum by culture. Nine yielded organisms completely or partially resistant to three antituberculous drugs; 36, to two drugs; 17, to one drug; and 21, to none of the drugs tested. In 5 patients resistance studies were not available. Organisms were tested with 10 mcg. per ml. of streptomycin, 10 mcg. per ml. of para-aminosalicylic acid, and 5 mcg. per ml. of isoniazid. The patients received various regimens of these drugs at the time of surgery. Pyrazinamide and neomycin were also given to selected patients whose organisms were resistant to other drugs.

From the Ray Brook State Tuberculosis Hospital, Ray Brook, New York.
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[*] At Ray Brook there has been no operative mortality in the last 209 consecutive resections for pulmonary tuberculosis.

Operative Spread of Disease.—This complication, manifested by the appearance in the postoperative roentgenogram of parenchymal shadows which had not been observed preoperatively, occurred in three instances. Changes were transient in 2 patients, and cleared following repeated endotracheal aspiration and continued antituberculous drug therapy (Fig. 1). Two of the 3 patients had sputum positive for tubercle bacilli at the time of surgery. One patient with positive sputum, whose operation was performed early in this series, developed permanent pulmonary changes following the spread of disease. Drug therapy in this instance was not adequate according to present standards. It would appear, therefore, that operative spreads are to a great extent reversible, especially when the tracheobronchial tree is maintained relatively free of secretions and effective drug therapy is administered.

In this series, as well as one previously reported,[1] spread of disease did not occur in any instance in which the prone position was employed on the operating table.[2] The Carlens double lumen catheter,[3] used in several instances, was apparently not as effective as the prone position as illustrated by the following case.

CASE REPORT

B. L., a 25 year old housewife, underwent a resection of the apical and posterior segments of the right upper lobe for pulmonary tuberculosis on Nov. 1, 1954. Sputum at operation and the resected specimen were negative on culture for tubercle bacilli. Postoperatively the patient developed a hemothorax and evidence of a bronchopleural fistula. Sputum was blood tinged and watery. Thoracentesis was unsuccessful because of the presence of clotted blood in the pleural cavity. On Nov. 8, 1954, the patient was taken to the operating room for a decortication and repair of the fistula. After endotracheal intubation the patient was turned from the supine to the left lateral decubitus position. Immediately, the tracheobronchial tree was flooded with pleural fluid. She was returned to the supine position, and the fluid was cleared from the respiratory passages. A Carlens catheter was passed, and the patient was again turned. Although the catheter appeared in proper position, with the balloons adequately inflated, fluid again poured into the dependent bronchi. The patient was quickly placed in the prone position with immediate improvement. The operation was then performed without further untoward incident.

Hemothorax.—Severe postoperative intrapleural bleeding occurred on seven occasions in this series. In five instances the patient was returned to the operating room and re-explored within a few hours of the original surgery. The blood clots were easily removed, and invariably the bleeders, when present, proved small and easily controllable. All of these patients did well. One patient was re-explored one week following resection (see Patient B. L.). In addition to the anesthesia difficulties, there was only fair postoperative re-expansion of the lung. One patient died without re-exploration. It is believed, in retrospect, that the fatal outcome might have been avoided had early re-exploration been performed. Because of experiences such as these, it is our policy to reoperate as soon as there is definite evidence of appreciable and continued bleeding. Use of the Bovie machine to coagulate chest wall bleeders during surgery has reduced the incidence of postoperative hemothorax.

Atelectasis.—More than transient atelectasis occurred in only 1 patient, who refused postoperative endotracheal aspiration. In all other instances endotracheal aspiration was effective in preventing or alleviating atelectasis. It

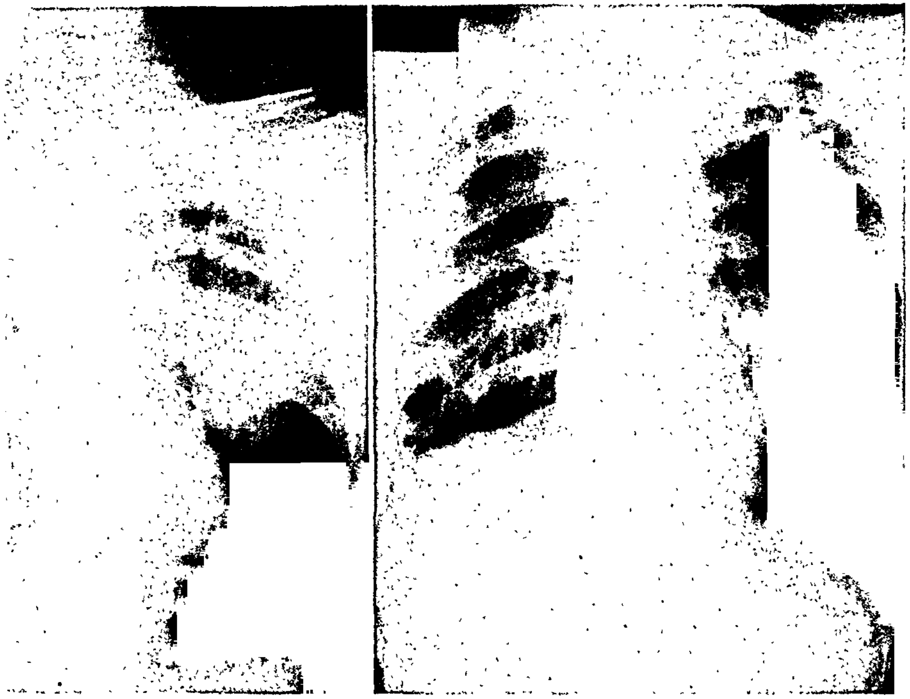

Fig. 1.—Operative spread of disease.
A, Preoperative roentgenogram.
B, Roentgenogram taken on the first postoperative day showing spread to left side.
C, Roentgenogram taken twelve days postoperatively showing complete clearing of the spread. This patient had negative sputum at the time of resection.

was necessary to perform tracheotomy on one occasion to facilitate frequent aspiration Other aids in preventing the occurrence of atelectasis were preoperative control of secretions by postural drainage and antibiotics, careful aspiration of the bronchial tree during anesthesia, and administration of anesthesia in a manner which would permit early return of consciousness postoperatively

Major Wound Sepsis—This complication occurred in five instances Three of these patients had culturable tubercle bacilli in the resected specimens, or sputum at the time of surgery Staphylococci were cultured from four wounds One wound yielded tubercle bacilli which were sensitive to the drugs administered Three of the wounds were débrided and closed secondarily Four wounds are now completely healed, and one is healed except for a small superficial portion

Bronchopleural Fistula and/or Empyema—Bronchopleural fistula, defined as a more than transient communication between the bronchial tree and the pleural cavity, occurred on twenty occasions Undoubtedly, unidentified fistulas occurred in the group of cases classified as residual air containing pleural spaces However, only proved cases of fistula are included in this analysis

The complications of bronchopleural fistula are summarized in Table II Tuberculous empyema occurred only in patients from whose sputum at the time of resection, or resected specimens, tubercle bacilli could be cultured Four of these patients still have "active" * disease In 3 patients the empyemas are small and improving One patient has had a recent additional resection and is now doing well † The only death occurred in a patient who refused treatment

Table III lists the therapy for bronchopleural fistulas and empyemas Although many surgical procedures are listed, all are designed to obliterate dead space, a fundamental principle in the treatment of empyemas

Residual Air Containing Pleural Space—Prior to the adoption of the routines to be discussed, residual air containing pleural spaces occurred quite frequently following resection It was formerly my practice to obliterate these spaces by thoracoplasty within a few weeks after resection, at which time the pleural cavity was often explored Not uncommonly, small air leaks could be demonstrated from the lung surface, even in cases where fistulas had been unsuspected clinically Thoracoplasty, with or without suture of the fistulas, was with few exceptions successful in obliterating the air spaces With the lapse of time it became obvious that in patients from whose sputum, or resected specimens, tubercle bacilli could *not* be cultured, tuberculous infection did not seem to occur Indeed, nontuberculous empyema rarely occurred, and such pleural air spaces have been observed for many months without complications *The presence of a bronchial communication rarely altered the situation* (Fig 2) On the other hand, when tubercle bacilli could be cultured from the sputum, or resected specimen, tuberculous empyema often occurred if the dead space was not quickly eliminated

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*National Tuberculosis Association (1950) Classification

†This operation is not listed in Table III since it has been performed too recently to evaluate results

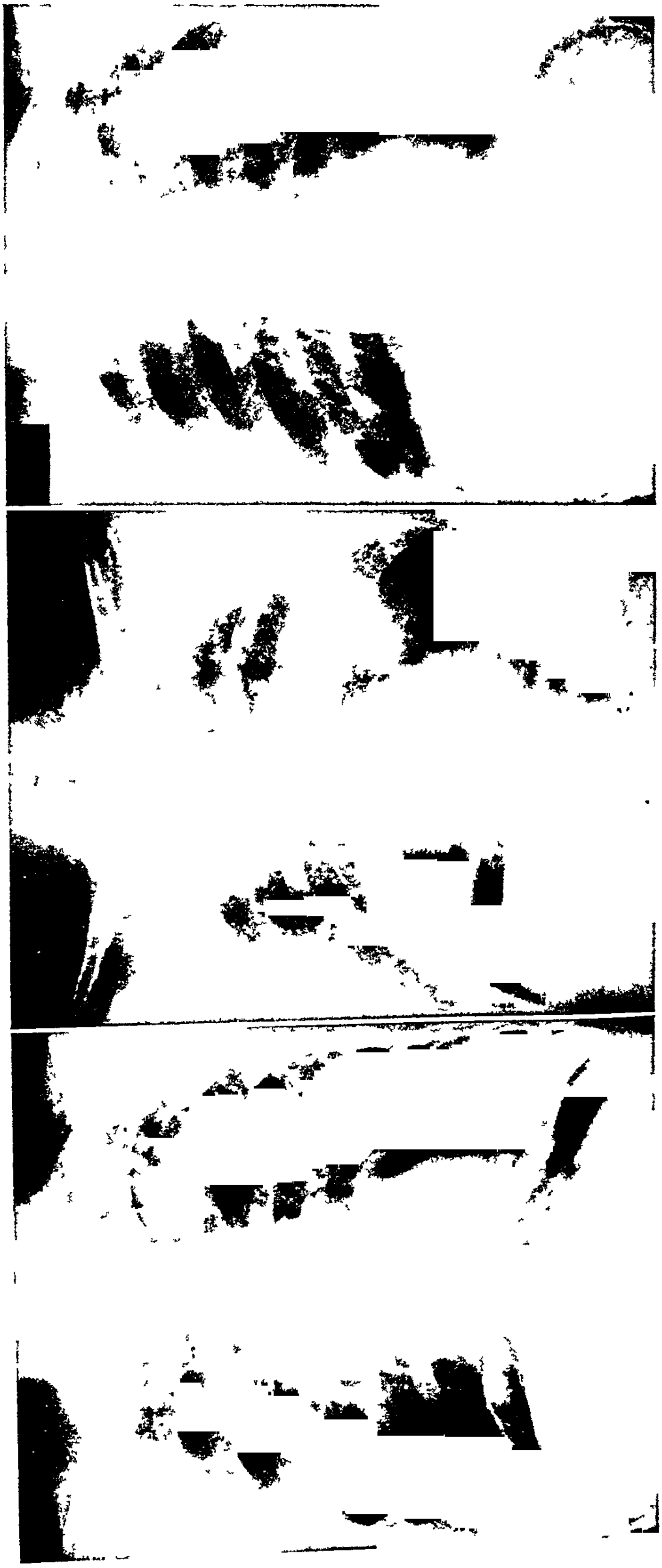

Fig. 1.—Operative spread of disease

A, Preoperative roentgenogram.

B, Roentgenogram taken on the first postoperative day showing spread to left side.

C, Roentgenogram taken twelve days postoperatively showing complete clearing of the spread. This patient had negative sputum at the time of resection was necessary to perform tracheotomy on one occasion to facilitate frequent aspiration. Other aids in preventing the occurrence of atelectasis were preoperative control of secretions by postural drainage and antibiotics, careful aspiration of the bronchial tree during anesthesia, and administration of anesthesia in a manner which would permit early return of consciousness postoperatively.

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*National Tuberculosis Association (1950) Classification.

†This operation is not listed in Table III since it has been performed too recently to evaluate results.

TABLE II. BRONCHOPLEURAL FISTULA

	PATIENTS	WITH NEGATIVE* CULTURES	WITH POSITIVE* CULTURES	WITH ORGANISMS* RESISTANT TO			WITH ORGANISMS* RESISTANT TO ALL AVAILABLE DRUGS AT RESECTION	RESULTS N.T.A. CLASSIFICATION (1950) OF PATIENTS AT LAST FOLLOW-UP			
				ONE DRUG	TWO DRUGS	THREE DRUGS		ACTIVE	ARRESTED	INACTIVE	DEAD
TOTAL	20	7	13	2	2	5	1	4	1	14	1§
A. With tuberculous empyema	7	0	7	2	1	1	0	1	0	5	1§
B. With probable tuberculous empyema†	4	0	4	0	1	3	1	3	0	1	0
C. With nontuberculous empyema‡	2	2	0	0	0	0	0	0	0	2	0
D. Without evidence of empyema	7	5	2	0	0	1	0	0	1	6	0

*Cultures for tubercle bacilli from resected lung or sputum at the time of resection.

†Although cultures of pleural space are not available, clinical evidence supports a diagnosis of tuberculous empyema.

‡Both of these were staphylococcal infections.

§This patient left the hospital about two weeks postoperatively.

TABLE III. THE TREATMENT OF TWENTY PATIENTS WITH BRONCHOPLEURAL FISTULA

TREATMENT	WITHOUT EVIDENCE OF EMPYEMA	NONTUBERCULOUS EMPYEMA (STAPHYLOCOCCUS)	PROBABLE OR PROVED TUBERCULOUS EMPYEMA		RESULTS N.T.A. CLASSIFICATION (1950) OF PATIENTS AT LAST AVAILABLE FOLLOW UP			
			RESISTANT* TO ALL DRUGS	SENSITIVE*† TO AT LEAST ONE DRUG	ACTIVE	ARRESTED	INACTIVE	DEAD
No surgical treatment	2			2	1	1	1	1§
Decortication	1	1					1	
Decortication and suture of fistula	3		1	2	1‡		6	
Decortication, suture of fistula and resection of lung				2	1‡		1	
Thoracoplasty	1			3	2		2	
Thoracoplasty and drainage of empyema			1		1			
Thoracoplasty, decortication and repair of fistula				1			1	
Thoracoplasty and decortication		1					1	
Thoracoplasty, additional resection and repair of fistula				1			1	

*Sensitivity of tubercle bacilli from sputum or pleural space to drugs available for treatment of fistula

†Organisms are considered sensitive to available drug not previously employed, when resistant studies are not available

‡These two "actives" represent failure of the procedure to cure the patient. Both patients later became "inactive" following other procedures

§This patient left the hospital about two weeks postoperatively.

Since the adoption of the following practices several years ago, persistent pleural air pockets have occurred infrequently. Space-filling thoracoplasty has been rarely necessary, except after pneumonectomy. The theoretically deleterious effects of overdistention on the course of tuberculosis in the remaining lung tissue have not been evident, in my experience or that of others.[4] At resection, the lung is freed sufficiently of adhesions to allow it to reaccommodate the pleural cavity. Chest wall bleeders are carefully coagulated with the Bovie machine. Following resection, air leaks are carefully controlled. Except following wedge resections, and in rare instances of advanced pulmonary emphysema, when air leaks are difficult to control, the raw surfaces of the lung are not approximated by suture. Two catheters are employed for drainage; the tip of one is sutured to the apical pleura, and the tip of the other is led to the base posteriorly I early abandoned under-water-seal drainage, as it depends for effectiveness on the ability of the patient to cough, which is often erratic in the early postoperative period when effective drainage is needed most. Moreover, with gradual pulmonary expansion, which often occurs when this type of apparatus is used, the base of the lung may become adherent in a position too far caudad to allow the pulmonary apex to reach the dome of the pleural cavity. Low negative pressures of −10 to −15 cm. of water have many of the same disadvantages, since the lung may not be held firmly in contact with the parietal pleura, a condition which promotes early agglutination of the pleural surfaces. Negative pressures of

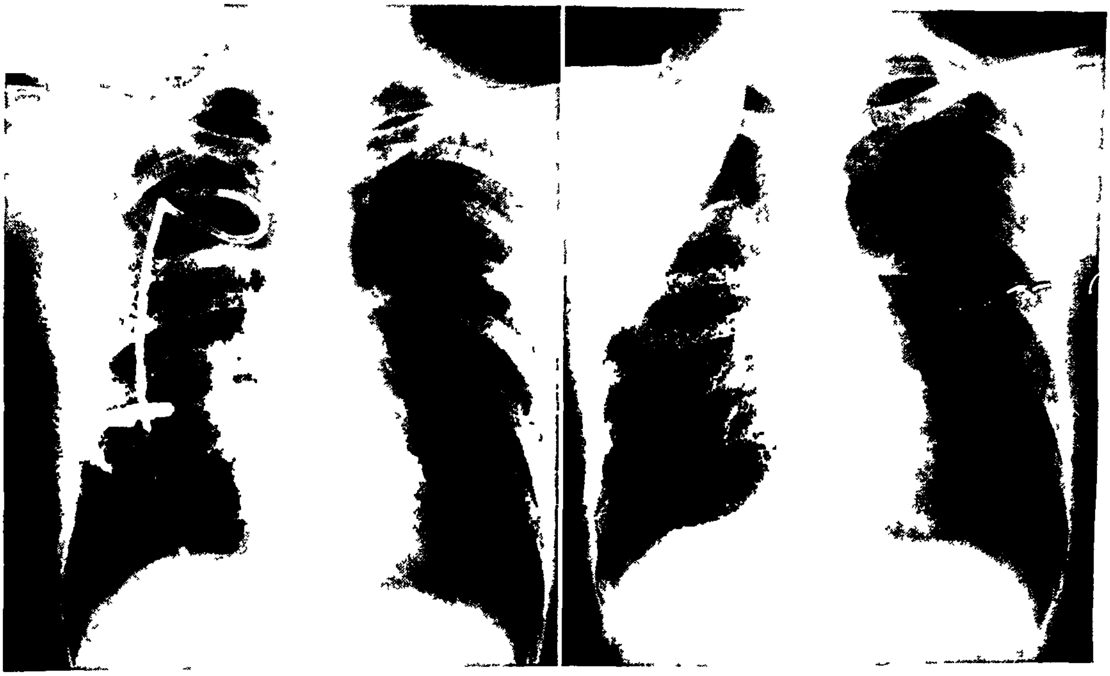
A B

Fig 2.—Bronchopleural fistula without empyema following resection of apical and posterior segments of right upper lobe Intercostal catheter suction (*A*) and thoracoplasty (*B*) were unsuccessful in obliterating the postoperative pleural air space

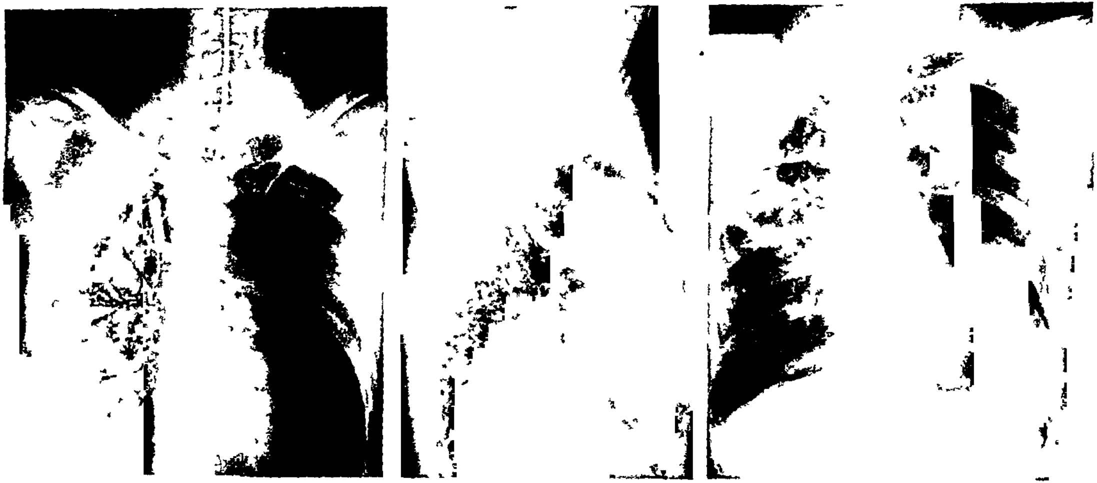

Fig. 2—Cont'd. (*C* and *D*) Fistula demonstrated by bronchogram. If fistula had not been demonstrated this might have been classified as a residual air containing space. (*E*) Eighteen months following thoracoplasty the pleural space has disappeared spontaneously.

–25 to –40 cm. of water are often necessary. However, the degree of negative pressure required may be reduced by maintaining the patient in a reclining position until air leakage and fluctuation of fluid in the drainage tubes have ceased.

As in complicated bronchopleural fistula, the most effective surgical procedures in the treatment of residual air spaces are thoracoplasty or pulmonary decortication with or without suture of fistulas, if present. Many spaces will disappear spontaneously (Fig. 2). Occasionally, before firm pleural symphysis has occurred, intercostal catheter drainage may be effective. However, prolonged intercostal drainage should be avoided as secondary infection may supervene.

Infected Emphysematous Bulla.—This complication occurred in 1 patient who had pulmonary emphysema. Tubercle bacilli were cultured from the resected specimen and from the bulla. The infection cleared after Monaldi drainage and further therapy with drugs to which the organisms were sensitive.

DISCUSSION

Complications following resection for pulmonary tuberculosis may be due to a number of factors. Surgical technique, choice of operation, diligence of pre- and postoperative care, and patient cooperation are some of the important ones which are difficult to measure. Complicating diseases often influence the outcome of a procedure. However, except perhaps for bacteriology, extent of disease is most important. Although it has been possible in this series, and in one previously reported,[1] to remove with good results cavitary disease, leaving behind appreciable residual nodular disease, it is to be expected that in these cases the incidence of complications will be higher than in those from which all palpable disease can be removed.

That bacteriology is an important consideration is indicated by the fact that tuberculous complications did not occur in this series in any patient from whose sputum at the time of surgery, or resected specimen, tubercle bacilli could not be cultured. Shefrin,[5] reviewing our surgical material, has found that tubercle bacilli can be cultured from 10 per cent of the resected specimens from patients whose sputum has been negative on culture for four months or longer prior to resection. It appears, therefore, that by proper selection of cases one can almost eliminate tuberculous complications.

Because of these considerations one should question the advisability of performing resection, in the absence of other compelling factors, upon patients with positive sputum who have received only one or two weeks of antituberculous drug therapy. The advocates of such early surgery have claimed that complications are fewer than if surgery were delayed until later, when patients may have drug-resistant organisms. There are several defects in such reasoning. First, after several months of continuous combined drug therapy the great majority of patients will have negative sputum. Some will have improved sufficiently to require surgery no longer. Those who do come to resection with negative sputum will be subjected to minimal risk of tuberculous complications Moreover, even if drug resistant organisms appear in appreciable numbers, it is rare that they are at once resistant to all available potent antituberculous drugs

SUMMARY

Early complications following resection for pulmonary tuberculosis occurring over a period of five and one half years are reviewed Prophylaxis and treatment are discussed

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RESTORATION AND RECONSTRUCTION OF THE TRACHEA AND MAIN BRONCHI

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ORGANIC obstruction of the trachea and of the main bronchi, requiring reparative surgical treatment is rare, and the experience in this field of any surgeon, in the less densely populated areas, must be limited. The local lesion is usually a sequela to accidental trauma, tuberculosis, or benign tumor. Local resection of a malignant tumor of the main bronchus is occasionally warranted in cases in which it is of paramount importance to conserve respiratory tissue and, at the same time, to give the patient a chance of surgical cure. In such rare contingencies, total ablation of the tumor with the involved lobe has been planned and reanastomosis of the upper or lower lobe bronchus, respectively, to the trachea performed.

These surgical developments have been the direct outcome of experimental work and clinical applications foreseen and practiced by Kirschner (1909), Hohmeier (1911), Neuhof (1917), Taffel (1940), and Daniel (1948). It was shown by Belsey (1946), in a report of the first extensive reconstruction of the human trachea, that immediate continuity could be restored by means of an airtight membrane (fascia lata) supported on a skeleton of wire along which normal mucosal continuity was effected by regeneration. Following further development of this concept by Rob and Bateman (1949) and by Gebauer (1950), authority has been given for the rapid clinical development of tracheobronchial resection and repair by suture and graft.

The successful development of homologous arterial grafts, preserved by tissue culture methods and by lyophilization, has not been reduplicated with bronchial tissue. Experimental grafting of autogenous and homologous tracheal segments has been unsuccessful in the main, the graft being replaced by granulation tissue without cartilaginous support, subsequently giving rise to respiratory obstruction.

In recent years, the clinical trial of tracheobronchial resection with resuture or graft, has been illuminated by the outstanding work of Gebauer (1950, 1953).

The scope of this paper is to discuss our limited experience in treating obstructive lesions of the trachea and main bronchi.

CERVICAL TRACHEA

Our clinical experience is only partly relevant to this paper. It is confined to the symptomatic treatment of asphyxia from compression, to the per-

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manent restoration and support of the tracheal lumen, and to the consideration of reconstruction in a case of carcinoma This is briefly summarized and reference is made to specific cases

Clinical material has been limited to 10 patients with constriction from thyroid adenomata, all of whom have been relieved, and the trachea restored by removal of the tumor via a collar incision in the neck, usually without recourse to splitting the sternum, to 1 patient with Hodgkin's disease of the thyroid gland, and to 1 patient with advanced carcinoma of the trachea There have been no cases of benign tumor (cylindroma) or of injury No local reconstruction has been performed

In the patient with recurrent thyroid carcinoma, involving the upper five rings of the anterior and lateral walls of the trachea (Case 1), resection and reconstruction was abandoned in favor of excision of the larynx and upper trachea, as the growing edge of the tumor could not be delineated

In the patient with Hodgkin's disease, the cervicothoracic trachea was compressed to an anteroposterior slit by a scirrhous tumor enveloping the visceral structures of the neck It was possible to free the trachea, the esophagus, and great vessels completely on their anterior and lateral aspects, and to anchor the thinned and collapsed cartilages by laterally placed sutures extending to the cervical tissues and close the wound without tracheotomy Convalescence was uneventful

In the other patient with advanced carcinoma of the trachea, a woman, 84 years of age, in whom there was a compression of the tracheal lumen to an anteroposterior slit by a large growth extending behind the esophagus, it was possible to relieve the obstruction by local removal of the growth from the neck using the usual incision combined with splitting of the manubrium sterni A tracheotomy tube was inserted on completion to allow time for healing There was considerable relief but there was rapid progression of the disease and an early death from tracheoesophageal fistula

Recurrent Carcinoma of the Thyroid—

CASE 1—G S, farmer, aged 64 The patient, referred by Mr P Eisdell Moore, was admitted to the hospital complaining of severe hemoptysis and hoarseness of the voice Thyroidectomy had been performed two years previously for carcinoma, and although he had been well for the following year, he was troubled by an occasional cough, huskiness of the voice, and an increasing swelling under the thyroid scar

On physical examination, there was a densely hard growth in the midline of the neck, fixed to the trachea and extending up to the thyroid cartilage and downward on the trachea The lower extremity reached to within 1½ inches of the sternal notch At bronchoscopy (a bloody affair), there was little movement of the vocal cords and just below them a friable, ulcerating hemorrhagic tumor was seen to occupy the anterior and lateral walls of the trachea for 1 inch

A full course of deep x ray therapy was given after which the growth was re assessed by bronchoscopy The vocal cords, although less mobile than normal, were considered to show improvement from the previous examination and the growth was thought to have become less extensive, less vascular, and more amenable to examination The tumor was seen to extend as a sessile, red, ulcerating mass to within 1½ inches of the glottis and to occupy the anterior and lateral aspects of the trachea for 1¼ inches The criteria for resection were fulfilled as the tumor appeared to be localized, anteriorly placed, did not involve the recurrent laryngeal nerves, and was so situated as to allow room for the insertion of an inlay below the cords.

Laryngectomy and excision of the proximal 2 inches of the trachea was performed after thoroughly exploring the possibility of local excision of the tumor and reconstruction of the trachea. A horseshoe incision with the two feet extending upward to the thyroid cartilage was made through densely fibrotic tissue to expose the operation site. Tumor or fibrous tissue was found to extend upward and to involve the upper five rings of the trachea, and the cricoid and thyroid cartilages on their anterior and lateral aspects, and there was an encapsulated and glandular mass above which there was considered to be carcinoma.

It was not possible to isolate the recurrent laryngeal nerves from this tissue during excision of the tumor mass from the anterior and lateral aspects of the trachea, cricoid and thyroid cartilages, at which sites there was no proper demarcation. The consensus of observers was that conservative operation would have been inadequate for carcinoma considering the risk of recurrence. Despite preparations for reconstruction by a dermis graft attached to tantalum mesh, the operation was abandoned in favor of laryngectomy with excision of the upper trachea, cricoid and thyroid cartilages, together with a block dissection of the upper deep cervical glands. The stump of the trachea was sutured to the skin after deepening the sternal notch. The pharynx was reconstituted and a Ryle's tube passed into the stomach for feeding purposes.

Comment: The convalescence of the patient was uneventful and speech became possible with an esophageal voice. There has been no recurrence (18 months). Under the circumstances, local resection would have been deplorable and contrary to the principles of cancer surgery which require a block removal of involved tumor together with the draining lymphatic glands. There would be few and very infrequent exceptions to this rule.

Tracheal reconstruction by a cylindrical dermis graft on tantalum mesh, as carried out in the cadaver and the pig (see Fig. 3), would have been suitable for a localized tumor of low grade malignancy, such as cylindroma or adenoma of the trachea. In such a case, difficulty would not be anticipated in displaying the recurrent laryngeal nerves. In the presence of malignant infiltration and fibrosis, this dissection is hopeless.

Hodgkin's Disease of the Thyroid Gland.—

CASE 2.—Mrs. F. S., aged 26. This patient was admitted in poor condition from the Cook Hospital (Dr. R. Hall) in considerable distress, suffering from respiratory obstruction with cyanosis, stertorous breathing, and a pulse of 120.

An attempt at thyroidectomy had been made a year previously. At this operation such insuperable difficulties were encountered owing to the hard, fibrous, infiltrating nature of the growth, that the operation was abandoned after ligature of the left internal jugular vein and injury to the left [illegible]urrent laryngeal nerve. A diagnosis of Riedel's struma and
kin's disease, respecti [illegible] as made by two independent pathologists.

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The compression was noticed to be mainly, but not entirely, from the left side. In the course of bronchoscopic examination, on the operating table under local anesthesia, performed in the sitting position owing to the patient's imminent danger of asphyxia, the tracheal lumen was visualized as a slit just beyond the glottis, the mucosa apparently not being involved.

A cuffed intratracheal tube was passed beyond the tumor and general anesthesia (Pentothal and curare) induced (Dr. Anson). The neck veins were greatly distended and bled freely although oxygenation was satisfactory.

With the patient in the semirecumbent position, the tumor was exposed by a collar incision with a T-shaped extension downward, dividing the sternum through to the third interspace and retracting the margins widely.

A massive, irregular, hard growth extending upward to the thyroid cartilage and downward to the tracheal bifurcation, especially on the left side where it had been demonstrated by x-ray, was found to encircle the trachea and the esophagus as well as the carotid sheath on either side, as a scirrhous collar, and to compress the great veins and aortic arch and its branches until the trachea was identified. It was possible to extricate the carotid sheath on either side from the encircling tumor. At this stage, the left jugular vein was noted to be a fibrous cord, a sequela of the previous operation. The tumor was densely adherent to, but not infiltrating, the trachea which was compressed so as to resemble a scabbard. It was freed in front and laterally, the tumor being divided at the posterolateral quadrants to avoid damaging the recurrent laryngeal nerves. The dissection was carried upward on either side removing the upper poles of the thyroid gland together with a few fleshy lymphatic glands in this region. Some apparently normal thyroid tissue was left at the upper pole on the left side.

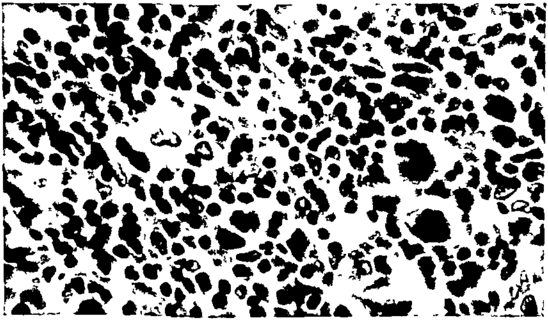

Fig. 1.—Case 2 (F. S.). Histologic section confirming the diagnosis of Hodgkin's disease.

By means of several sutures placed between the lateral walls of the softened trachea and the adjacent fibrous tissue, the walls were fixed apart to establish a lumen. The sternum was approximated with wire sutures and the skin closed, leaving two small open drains into the anterior mediastinum. After removal of the intratracheal tube, there was a normal air passage and the patient was returned to the ward and placed in an oxygen tent.

A course of deep x-ray therapy to the neck was given for Hodgkin's disease and her immediate recovery was uneventful. Cellular elements, typical of Hodgkin's disease, infiltrating and largely replacing the thyroid gland (Fig. 1), were confirmed by Dr. S. Williams after histologic examination of the specimen. She remains well.

Comment: 1. The trachea was compressed by the tumor (as distinct from infiltration by carcinoma) and the obstruction was relieved by removal of the tumor. 2. Tracheotomy was not possible and indeed undesirable, either before or after the operation. 3. Anesthesia was made possible by the insertion of a McGill tube under local anesthesia with the patient in the sitting position. 4. After operation, it was found possible to support the flaccid trachea by laterally placed sutures. If these had not been satisfactory, it was planned to splint the tracheal walls with steel mesh.

Discussion.—Local excision and reconstruction is reserved for patients with low-grade local malignancy, which as a group, do not respond favorably to deep x-ray therapy. The local extensibility of the trachea makes it possible to excise 1 inch or more of trachea and to reanastomose the ends (Fig. 2). This is facilitated if the posterior wall is able to be preserved.

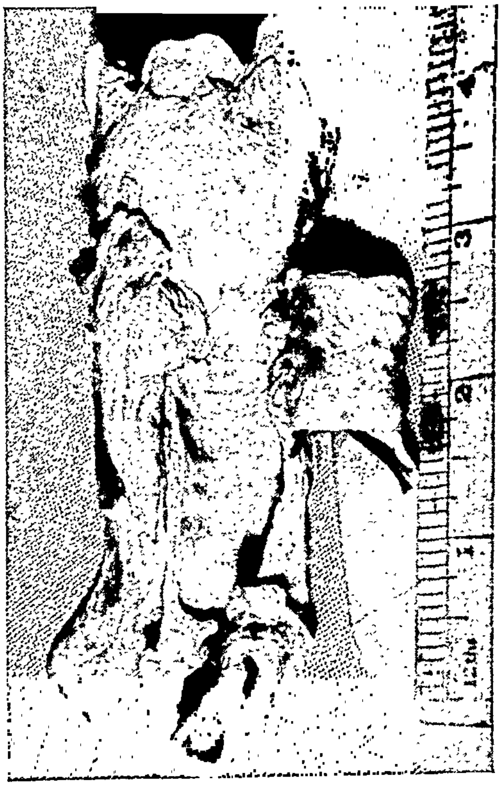

Fig. 2.

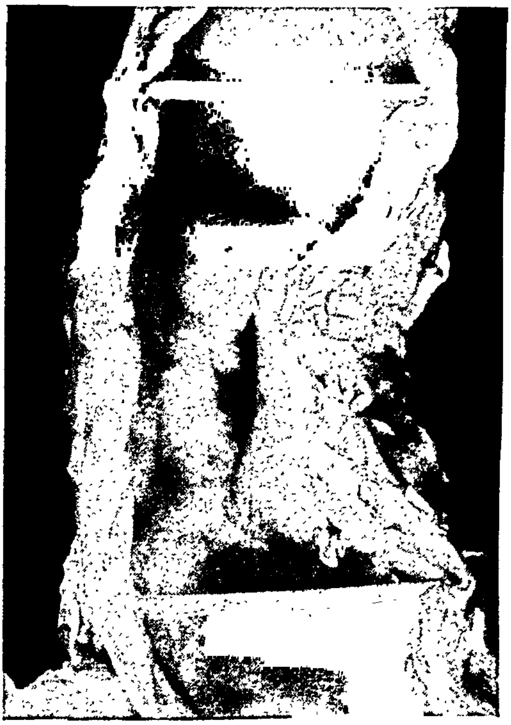

Fig. 3.

Fig. 2.—Human trachea after excision and reanastomosis of the ends. Post-mortem specimen.

Fig. 3.—Cervical trachea of a pig opened from behind. Sacrificed six weeks after excision of the anterior and lateral walls and restoration by a tantalum supported dermis graft. The mucosa has almost regenerated over the tantalum mesh.

In other cases, defects, which have been left after excising the tumor, can be satisfactorily sealed by using an airtight patch of dermis supported on the inner aspect with tantalum mesh (Fig. 3).

In the presence of inoperable malignant disease, tracheotomy is to be avoided if possible as the tube interferes with radiation of tumors, which are usually resistant anyhow, and malignant cells are likely to grow along the sinus.

Local measures may be necessary to support a flaccid trachea after removal of a tumor compressing it.

THORACIC TRACHEA

Experience in reconstituting the thoracic trachea has been limited to three cases, each of which presented a different problem: (1) Local excision of a tracheal carcinoma and repair using a free graft (Case 3). (2) Local plastic reconstruction by a longitudinal incision and transverse suture (Case 4). (3) Tracheal replacement by insertion of a viable bronchotracheal graft to replace tissue lost by stricture (Case 5).

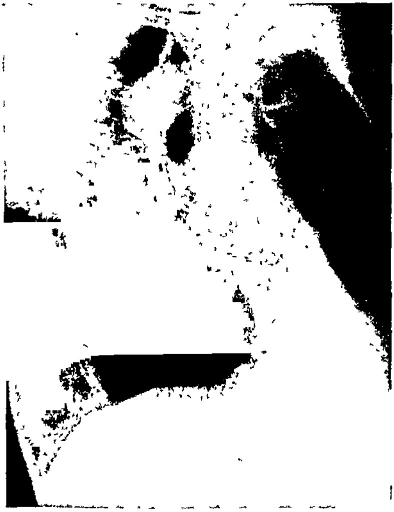

Fig. 4A.—Case 3 (I. B.). Primary carcinoma of the trachea. Lateral chest x-ray showing the position of the tumor.

CASE 3.—I. B., aged 58, medical practitioner. The patient was a heavy smoker. There was a history of cough becoming increasingly severe over the past few months, loss of appetite, and loss of weight and stridor.

Physical examination: There was little of note apart from a hard gland in the supraclavicular region which was reported as showing chronic granulomatous changes. A circumscribed mass was demonstrated radiologically in the superior mediastinum between the esophagus and the trachea and just above the aorta (Fig. 4A). The Wassermann reaction was negative. At bronchoscopy (Dr. McDowell), a rounded, firm, nodular tumor, about 2 inches in diameter, was seen protruding through the right posterolateral wall of the thoracic trachea and extending downward to just above the carina. At thoracotomy (Oct. 25, 1950—Mr. D. Robb and R. N.), a hard, irregular, rounded tumor was felt arising as an oval projection 2½ inches in length from the right side of the trachea and extending upward from just above the curve of the azygos vein. The overlying lung, adherent but not infiltrated, was excised and examined. An intratracheal tube was able to be manipulated so that the tip passed beyond the proposed excision of the trachea leaving the balloon adjacent to the deficiency. An oval window of trachea containing the tumor, together with a piece of esophagus, was excised. The defect in the trachea was closed at either end by direct suture and the central deficiency filled by a firm patch of atelectatic middle lobe of the lung covered by pleura on both sides. The esophageal wall was reconstituted by suture.

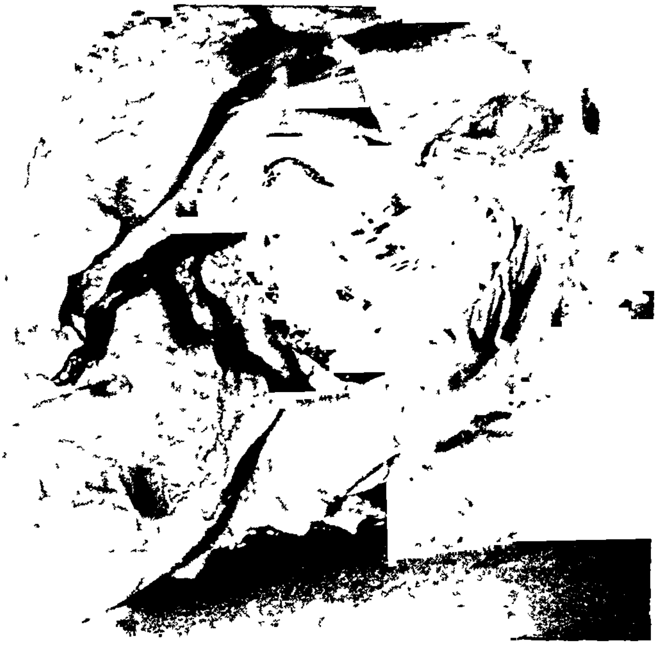

Fig. 4*B*.—Cardiac embolus which caused sudden death.

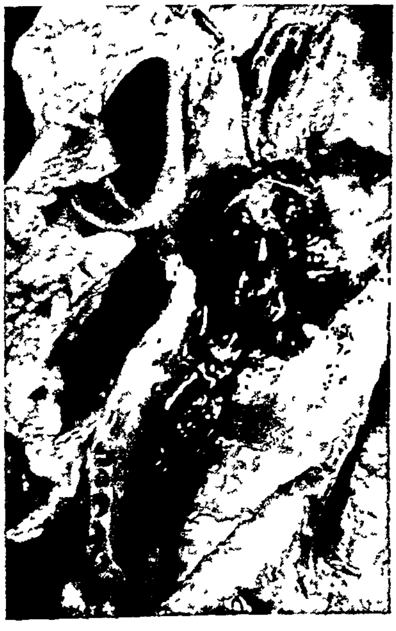

Fig. 4*C*.—Post-mortem specimen of the trachea showing the position from which the tumor was excised and the well-sealed tracheal deficiency.

The specimen was reported as being an anaplastic carcinoma of the trachea apparently of basal-cell type with malignant infiltration of the esophagus.

Apart from tachycardia and a temperature rising to 100° F, the postoperative recovery was uneventful until the eighth day when sudden death occurred

At post mortem, there was an acute obstruction of the heart by a cardiac embolus 14 inches in length arising from the inferior vena cava (Fig 4*B*) The tracheal lumen, slightly narrowed above and below by sutures, showed an oval window 1½ inches in length by ¾ of an inch in width, repaired by a patch of lung covered on the pleural surface by a smooth layer of fibrin (Fig 4*C*) There were residual malignant glands all along the trachea By histologic examination, there was shown to be a tissue reaction of the perichondrial supporting tissues of the trachea infiltrating into the necrotic patch and characteristic of the early stages of repair

Comment: A patch of firm lung tissue was found to seal the tracheal defect, pending natural repair This technique originally used for reinforcing the raw bronchial stump (Churchill, 1939), has been superseded by methods in which the tracheal lumen can be reconstituted and maintained regardless of the amount of tissue excised

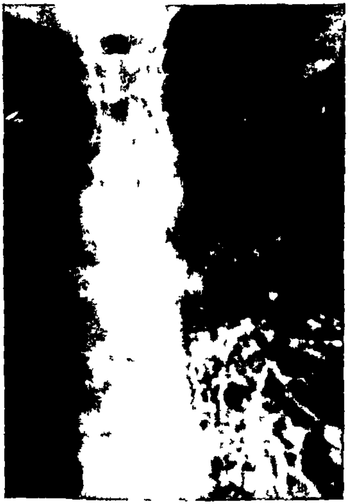

Fig 5A—Case 4 (B L) Tracheogram showing tracheal stenosis opposite the inner end of the clavicles

Case 4—B L, aged 24, occupational therapist This patient had pulmonary tuberculosis, first recognized in 1947 at which time an x ray of the chest showed minimal infiltration and sputum tests were positive Symptoms of persistent cough and inspiratory stridor together with a wheeze and dyspnea were first complained of in October, 1953, and despite ten weeks' treatment with streptomycin 1 Gm three times weekly, and para aminosalicylic acid, there was no improvement At bronchoscopy (Dr C McDowell), 2½ inches from the vocal cords, the tracheal lumen was seen to be reduced to about 5 mm in diameter by tuberculous granulation tissue reminiscent of polyps This was treated locally by painting with 30 per cent silver nitrate, and systemically by antituberculous drugs After one month of treatment, there was still a severe stridor, and at bronchoscopy, the presence of

a fibromembranous stenosis was seen, 1½ cm. above the carina. After negotiation of the stricture by the bronchoscope, the right stem bronchus was shown to be narrowed at its entrance, but covered by healthy mucous membrane.

There was progressive increase in stridor and respiratory distress over the next two months, and at a later bronchoscopy, the membranous tracheal stenosis was shown to be almost complete. The stricture was graphically visualized by tomography and by a tracheogram (Fig. 5*A*). Operation was undertaken on Dec. 21, 1953.

The chest was opened through the sixth intercostal space *removing segments of the* second to sixth ribs, posteriorly. The lung, reasonably healthy in apearance, was freed in the extrapleural plane and the azygos vein divided between ligatures. The thick vascular pleura over the trachea was incised to the thoracic inlet to give better exposure. After incision and dissection of the peritracheal fascial envelope, the fibrous stenosis was found (Fig. 5*B*). It was without supporting cartilaginous rings and about ¾ of an inch in length. After insertion of traction sutures into the adventitia and palpation of the upper end of the stricture, a transverse incision was made into the trachea immediately above this and a vertical extension made downward for 1 inch, dividing the stricture visible as a fibrous ring 3 mm. in diameter. The intratracheal tube was advanced down the left bronchus and respiration resumed without any air leak despite the lack of cuff. A gap in the trachea, 1½ inches long but with the posterior wall intact, was now present but sealed with the intratracheal tube. The trachea having been mobilized up to the neck earlier in the operation, and a rubber loop having been placed for traction, it was found possible to

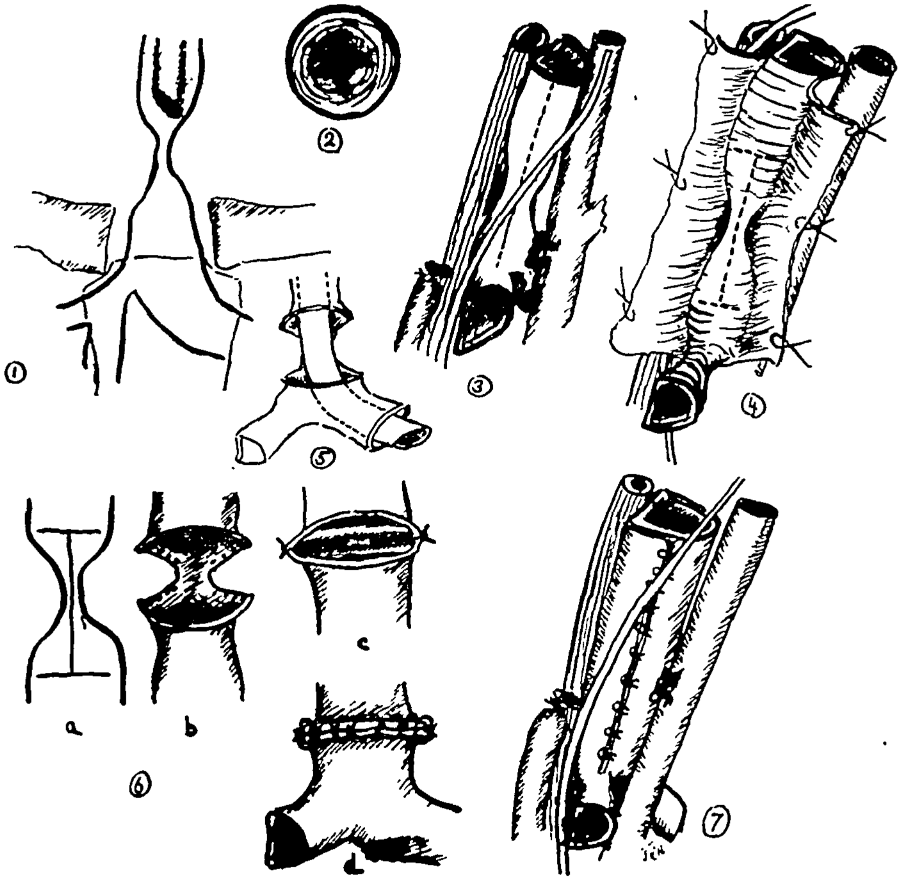

Fig. 5*B*.—Case 4 (B. L.). Diagrammatic outline of the steps in the reconstruction. The intratracheal tube is in position, *1*; above the stricture, *2*. The appearances at thoracotomy after ligation of the saphenous vein are shown in *3*, and after reflection of peritracheal fascia in *4*. The stages in the tracheoplasty are shown in *6 a,b,c d*. The final appearances are shown in *7*.

draw the upper and lower edges of the tracheal incision together by everting mattress sutures, thus completely relieving the stricture. On completion, the intratracheal tube was pulled up and the anastomosis tested. After suture of the peritracheal fascia, the pleura was reconstituted. The upper lobe bronchus was healthy but narrow.

The postoperative course was uneventful and the symptoms were completely relieved.

The patient was readmitted urgently on March 11, 1954, with asphyxial symptoms and at bronchoscopy the operation site was obliterated by large edematous polypoid granulations over the black silk sutures protruding into the trachea. After removal of these watery polyps, the tracheal lumen was shown to be entirely satisfactory. There have been further bronchoscopic examinations from time to time with removal of granulations and of stitches divided by a special stitch-cutter (*Fig. 5C*), and cauterization with 30 per cent silver nitrate. The condition has healed and has required no further treatment over the past seven months (Fig. 5*D*).

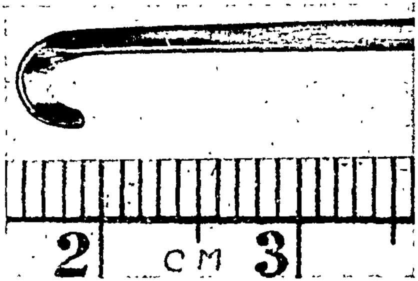

Fig. 5*C*.—Photograph of stitch-cutter described in the text.

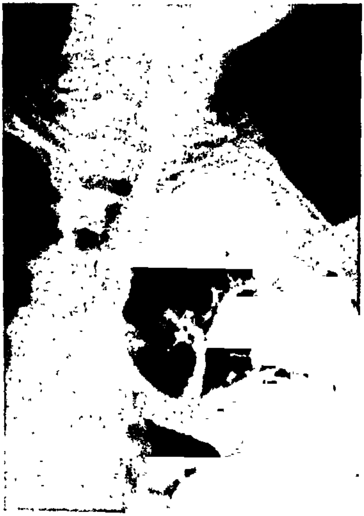

Fig. 5*D*.—Postoperative tracheogram a year later showing restoration of the normal lumen.

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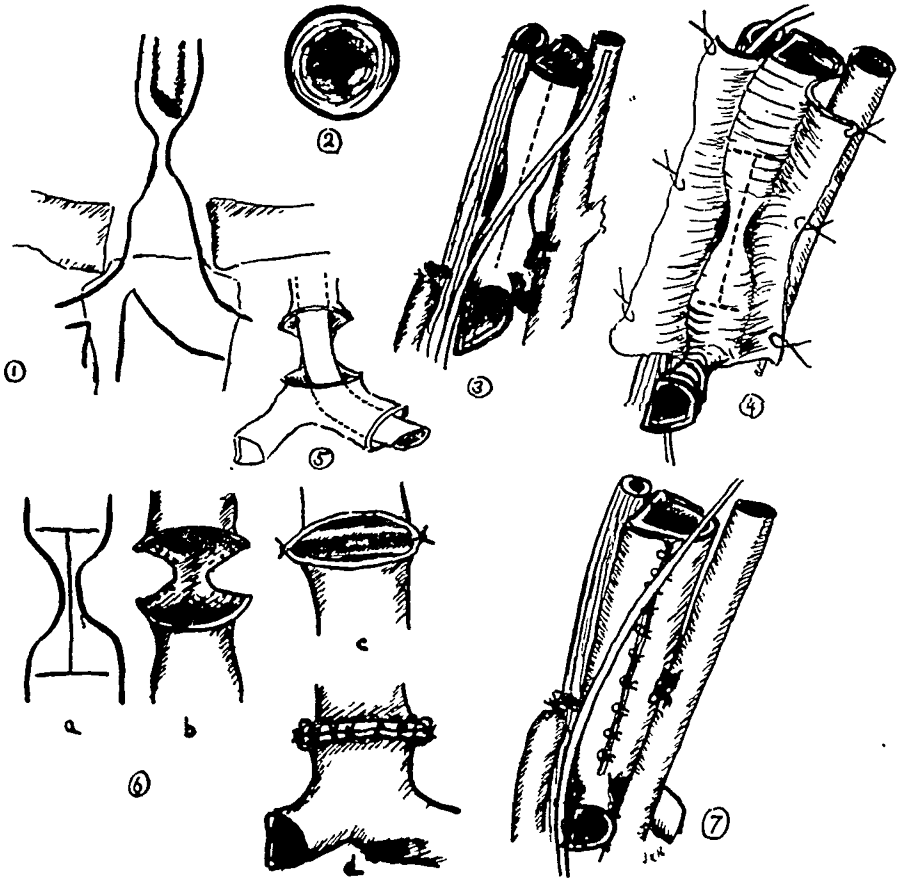

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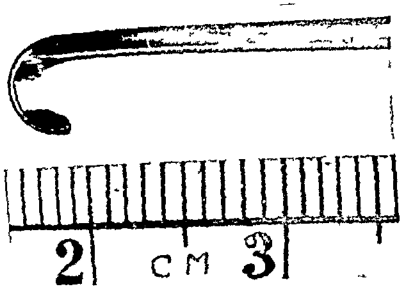

Fig. 5C.—Photograph of stitch cutter described in the text.

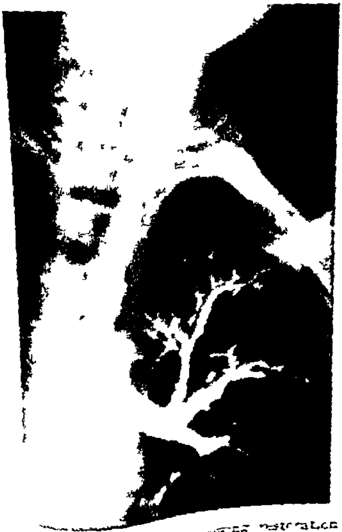

Fig. 5D.—Postoperat[illegible]gram a year after [illegible] restoration of the normal lumen.

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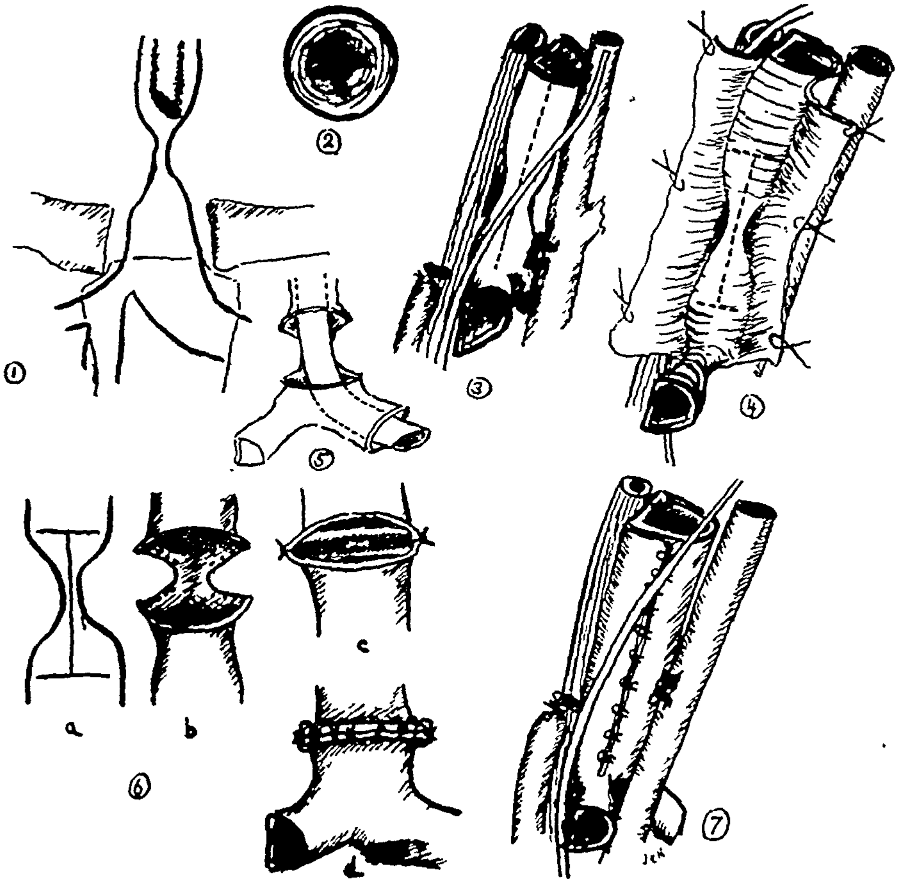

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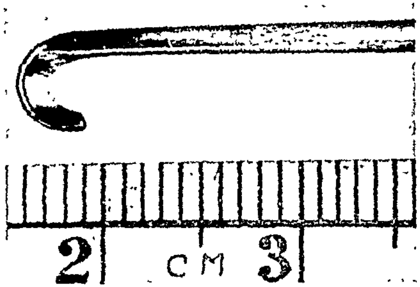
The patient was readmitted urgently on March 11, 1954, with asphyxial symptoms and at bronchoscopy the operation site was obliterated by large edematous polypoid granulations over the black silk sutures protruding into the trachea. After removal of these watery polyps, the tracheal lumen was shown to be entirely satisfactory. There have been further bronchoscopic examinations from time to time with removal of granulations and of stitches divided by a special stitch-cutter (Fig. 5C), and cauterization with 30 per cent silver nitrate. The condition has healed and has required no further treatment over the past seven months (Fig. 5D).



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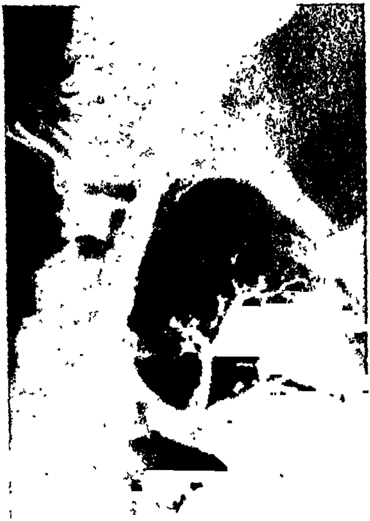

Fig. 5D.—Postoperative tracheogram a year later showing restoration of the normal lumen

Comment: (1) The local endobronchial disease occurred without serious general disease possibly from the submucosal spread from the *lymphatics* of the upper lobe of the lung. There was local clearing of the disease following applications of silver nitrate and the giving of antituberculous drugs, but the stricture formation was progressive with healing. (2) The extensibility of the trachea was quite remarkable. This fact was made use of in the repair which at first sight seemed impossible. The plastic operation was found to be easier than complete division. (3) There was considerable polypoid reaction about the stitches. Obstruction was caused and asphyxia only averted by urgent bronchoscopic removal. There was difficulty in removing the stitches in the initial stages but this problem was solved by the use of the special stitch-cutter.

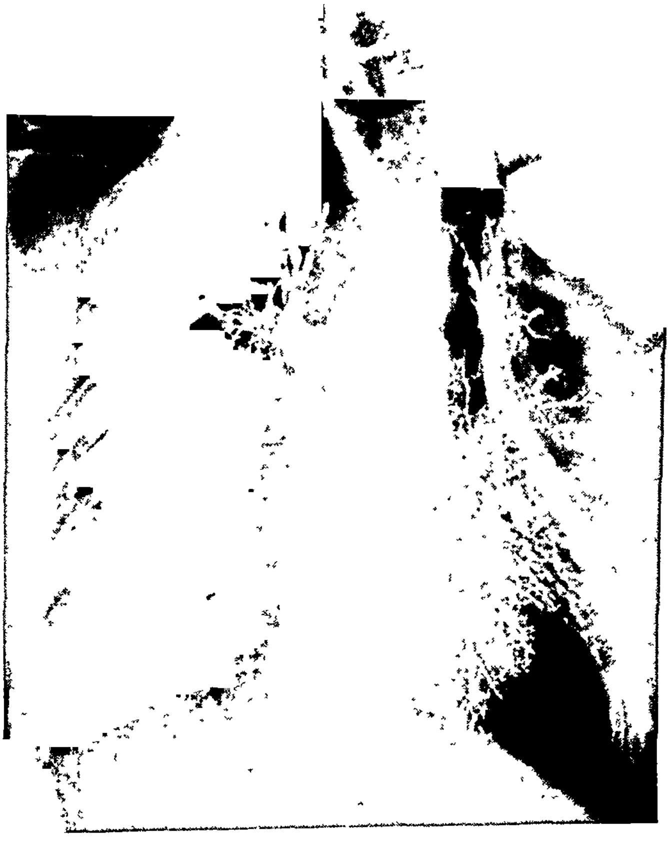

Fig. 6A.—Case 5. Tuberculous stenosis of trachea and left stem bronchus. Before operation.

Case 5.—M. R., a 22-year-old woman,* gave a history of tuberculosis, complicated by asthma since 1944 at which time a right artificial pneumothorax was induced for infiltration of the upper and middle lobes of the lung. There was deterioration in 1948, at which time there was shown to be a cavity in the left upper lobe, 2 inches in diameter, for which a seven-rib thoracoplasty was performed with subsequent conversion of the sputum. The right artificial pneumothorax was discontinued in 1950, the patient remained well until 1952 when severe asthma and a wheeze was noticed. At this time, the trachea was seen, at bronchoscopy, to be narrowed to the diameter of a lead pencil by scarring and active tuberculous granulations which extended upward from the carina for 2 inches Treatment with streptomycin and isoniazide was continued for six weeks, at the end of which time, although the sputum was negative, there was considerable stridor

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*Case history published in the Brit. J. Surg. 42: 174, 1955.

The patient was admitted urgently in May, 1953, suffering from asphyxia which was relieved by sedation and oxygen The tracheal lumen was seen, at bronchoscopy, to have undergone progressive narrowing without ulceration to the size of a goose quill, at the site previously mentioned A visual record of the lesion was obtained by a bronchogram Tracheal stenosis, 2 inches in length, was demonstrated extending upward from the carina (Fig 6A) There was an apparently normal segment of the left stem bronchus below this and proximal to a second stenosis at about the origin of the left upper lobe bronchus There was some distention to the right bronchial tree

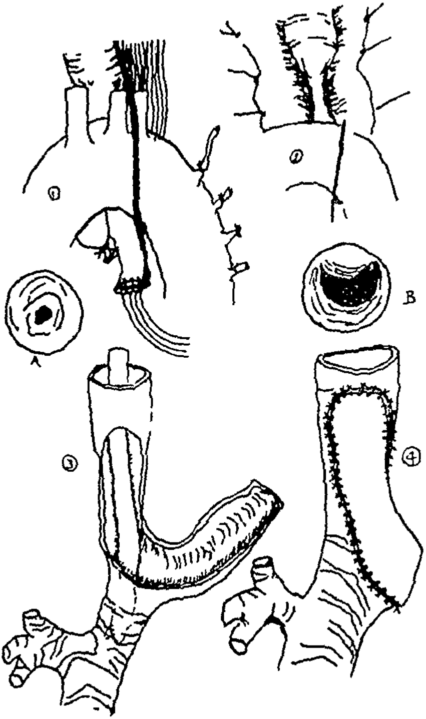


Fig 6B—Diagram summarizing the lesion and steps in the operation

The whole of the mind of this patient was concentrated on breathing An immediate sensation of asphyxia would be precipitated by excitement or talking She was cyanosed and with forced respiration, stridor was audible from a distance

Operation It was thought that a satisfactory inlay could be provided by a pedicle graft of healthy living bronchial stem on the left side across the stenosis The operation had been carried out under post mortem conditions where details of surgical technique and anesthesia had been elaborated

The left chest was opened under local anesthesia (Dr. Watt) through the original thoracoplasty incision. The lung was dissected free, excised at the stenosis, and the long bronchial stump sutured. The loops of the sutures were left uncut, so that it was possible for them to be passed under the aortic arch after this had been mobilized and the bronchus withdrawn above. The mediastinal pleura overlying the trachea was incised and the stenosis recognized as an elongated constriction 1 inch above the aortic arch. The left bronchus and the trachea were incised on the posterolateral aspect right up beyond the stricture and the intratracheal tube advanced down into the right bronchus to maintain respiration. The inlay of the bronchial flap into the trachea and across the stricture was accomplished by tying previously placed everting mattress sutures. These were reinforced by interrupted nylon sutures placed at intervals round the pedicle. The mediastinal pleura was sutured and the chest closed with underwater drainage to allow the negative intrathoracic pressure to expand the graft (Fig. 6*B*).

At postoperative bronchoscopy, a crescentic tracheal lumen was visualized and the bronchoscope was passed beyond with ease. During the first forty-eight hours, the patient was nursed in an oxygen tent. She gained strength rapidly and convalescence was uneventful. Nutrition improved with a 10-pound gain in weight in the first two weeks after operation (Fig. 6*C*).

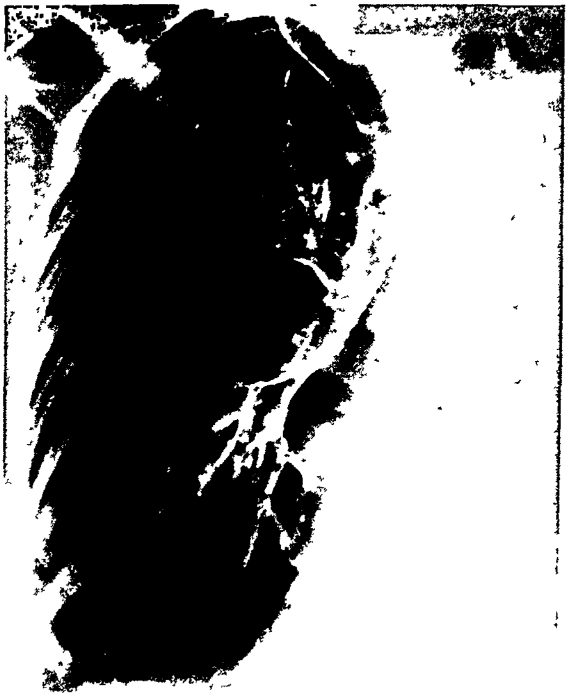


Fig. 6*C*.—One year after left pneumonectomy and restoration by a living graft of the left stem bronchus.

The patient's present state, June, 1955, two years following operation, was recorded as follows: "The lumen in the trachea in the region of the stenosis is normal except for a rounded bulge or dimple where the left bronchus has been drawn upward to provide an inlay. The patient is well and working."

Discussion.—In each case presented, reconstruction has been possible without interruption of the trachea.

A patch of lung was found to provide satisfactory closure without encroachment on the lumen (Case 3), but this expedient has now been superseded by the use of a wire mesh prosthesis covered by autogenous dermis graft which is molded as a reinforced patch onto the intratracheal tube so as to overlap the defect. Epithelization of the tracheal lumen is accomplished by regeneration of the mucosa over the wire mesh. Wire-supported dermis graft (Gebauer) is just as effective. For localized constrictions, resection and anastomosis has been practiced successfully. Bearing in mind that the defect is much greater after division and release of the stricture, the maintenance of the ends in approximation posteriorly as was done in Case 4 may be found advantageous.

The principle of reimplantation of the bronchus to the trachea across this stricture, akin to a Finney pyloroplasty, has been successfully applied by Gebauer (1953).

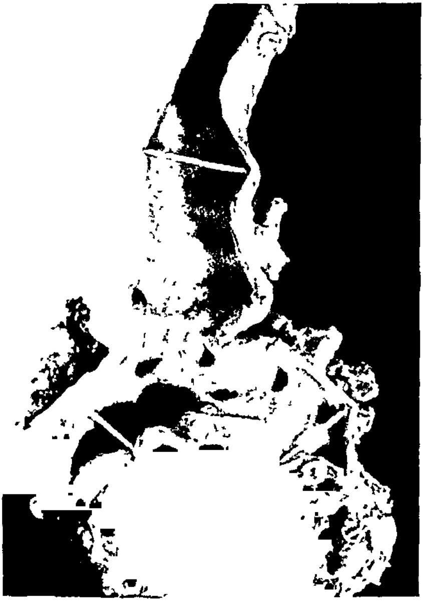


Fig. 7.—Post-mortem specimen of tracheobronchial tree of pig removed three months after excision of the tracheal bifurcation and reconstruction performed under hypothermia at 80° F. The repair is almost perfect.

The cure of a long tracheal stenosis was accomplished by insertion of a living bronchial graft (Case 5), a procedure which was later found to have been employed unsuccessfully, but recommended for clinical trial by Kergin (1952).

Complete excision of the segments and restoration of the continuity has been accomplished by plastic prosthesis, by Grindlay, Claggett, and Moersch (1948), and Craig and associates (1949); by supported autografts of fascia (Belsey, 1946; Rob and Bateman, 1949); and, of dermis (Gebauer. 1950).

Direct suture is facilitated by approximating the ends with previously placed wire tension sutures after careful mobilization above and below. The formation of polypoid granulomas is avoided by using multistrand wire and fine plaited nylon sutures and everting the edges as much as possible.

Reconstitution by a permanent prosthesis is to be avoided if possible, owing to the danger of late dislocation of the prosthesis from its bed of scar tissue, and subsequent tracheal stenosis in this site, as experienced by Craig and colleagues (1951), but it has been suggested as an initial treatment in operations involving extensive obstruction of the trachea by a new growth and later replaced by a well-supported dermis graft, Gebauer (1951).

Resection of the bifurcation and reconstitution of the trachea has been worked out in the cadaver and successfully performed under hypothermia at 80° F. on a pig. Oxygen was delivered by means of an intratracheal tube in the usual manner until the right chest was opened. By dividing and cannulating the right bronchus and connecting this to a separate anesthetic machine, temporary oxygenation was maintained, while division of the trachea, together with the bifurcation, was accomplished and the upper intratracheal tube advanced into the left main bronchus. After mobilization and approximation of the left bronchus to the trachea, the cannula was removed from the right bronchus which was then sutured to the left in a double-barrelled manner, and both in turn sutured to the trachea (Fig. 7).

It is considered that in such a special case, deliberate surgery will be found possible under hypothermia and the harmful effects of suboxygenation on the respiratory and vasomotor centers avoided.

MAIN BRONCHI

Opportunities for conservative surgery are few, and only present as localized benign obstructive lesions in which the peripheral bronchial tree is undamaged. Such conditions may result from adenoma or stricture and also from rare cases of malignancy in which adequate excision of the tumor combined with conservation of a healthy lobe is desirable owing to limited respiratory reserve.

Case 6.—*M. McK., 56 years old, housewife, was admitted on July 10, 1954, complaining* of wheeze and recurrent episodes of fever over a period of seven years following the diagnosis of pulmonary tuberculosis which were relieved by coughing up large amounts of mucopus.

She was treated for twelve months with streptomycin and para-aminosalicylic acid. The sputum was converted and has remained consistently negative.

At bronchoscopy (Dr. C. McDowell), the left main-stem bronchus, 1.5 cm. from its origin, was shown to end in a firm, smooth, fibrous stenosis 2 mm. in diameter. The presence of a localized stenosis, 1 cm. below the carina, was confirmed by a left bronchogram, the bronchial lumen widening below to connect with the normal left upper lobe. The lower lobe bronchus was completely stenosed (Fig. 8A).

At operation, performed July 29, 1954, the left lower lobe was completely collapsed beyond the bronchostenosis and the presence of a further stricture in the left stem, unsupported by cartilaginous rings, verified 3.5 cm. proximal to the upper lobe bronchus.

It was thought possible to perform lower lobectomy of the collapsed and bronchiectatic lower lobe and to conserve the upper lobe by a plastic operation on the main bronchus. After lower lobectomy, the open left stem bronchus was incised posteriorly upward beyond

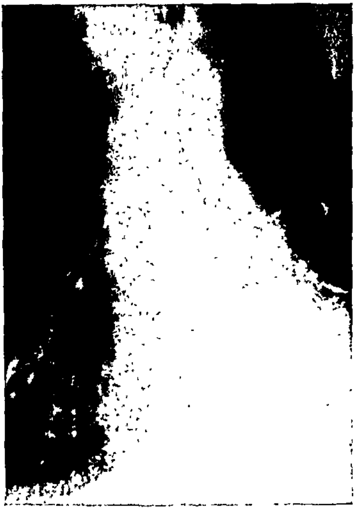


Fig. 8*A*.—Case 6 (M. McK.). Tuberculous stenosis of left stem bronchus (partial) and of the left lower lobe bronchus (complete). Bronchogram before operation.

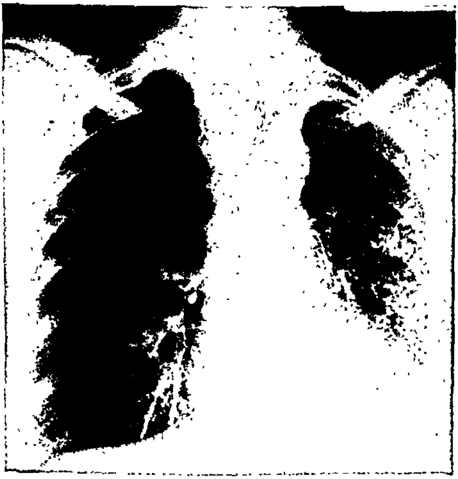
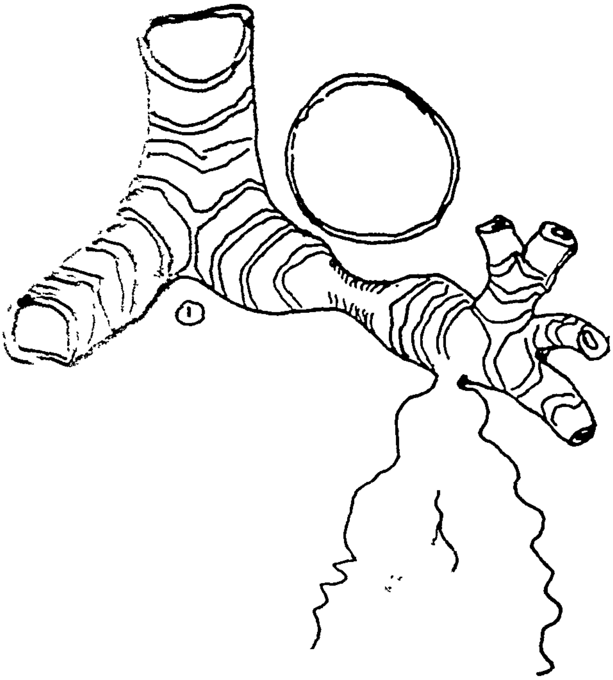


Fig. 8*B*.—After left lower lobe lobectomy and plastic reconstruction of the left stem bronchus.



Preliminary lobectomy, conserving as much bronchial tissue as possible, was helpful.

The preliminary placing of stout silk sutures between the upper lobe bronchus and the stem bronchus above the stenosis, and also the manual elevation of the lobe and its bronchial stem taking the tension as the sutures were tied, enabled the procedure to be performed when otherwise it would have been difficult, obscured as it was by the aortic arch.

Discussion: If the local disease is benign and the peripheral lung tissue is healthy, resection and anastomosis are desirable. Operative mishaps in which the bronchus is inadvertently divided so as to exclude or narrow the entrance to a healthy lobe should be repaired immediately to forestall the otherwise most unhappy sequelae of collapse, pneumonitis, and empyema (Fig. 9).

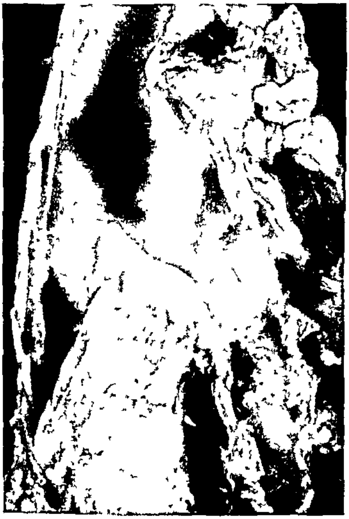


Fig 9.—Right upper lobe bronchus of pig removed 3 months after complete section and resuture showing complete normal healing without narrowing of the lumen.

Traumatic bronchial injuries may be confirmed bronchoscopically and urgent operation undertaken to restore continuity. Even at a late stage when the disrupted ends have become buried in scar tissue, a healthy lobe may be restored by anastomosis of the divided bronchi.

A note of caution is sounded in dealing with benign tumors of the bronchus for, in our series of cases, there has been bronchiectasis and suppurative changes peripheral to the obstructive lesion in all. In one case, there were involved glands and the patient died of secondary deposits within two years. In another case, seemingly ideal for local treatment, the lobe had to be removed, after bronchotomy with resection of the tumor and its pedicle, as it could not be inflated. The operation specimen was shown to be partially destroyed by bronchiectasis and emphysema and the excised tumor was identified as a low-grade malignant cylindroma.

A classic reconstruction for benign tumor has been reported by Officer Brown (1954). After local excision of an adenoma involving the bronchus to the upper lobe, the apical segment of the lower lobe, and the basal segments, reconstruction of the entire lung was successfully accomplished by suturing the divided distal bronchi together as a multibarrelled unit which was then anastomosed with the left main bronchus.

It has been shown on the cadaver that radical lobectomy of both upper and lower lobes, so as to include a large bronchial segment together with the involved lymphatic glands extending into the mediastinum, can be accomplished if local conditions are favorable and the overriding necessity of preservation of pulmonary tissue is present.

Experience has confirmed bronchial resection and anastomosis to be much more successful than repair by graft. Retraction of the divided ends may be prevented by the plastic procedure described in Case 4. If actual resection and reanastomosis is required, it has been found of considerable help experimentally to have a wide exposure of the bronchi, to have adequate control of the ends by traction sutures before division of the bronchus, to keep close to the lesion, and to place all the difficult sutures in position before any one is tied. For complicated reconstruction, the formation of a multibarrelled anastomosis is likely to be helpful. In cases of disproportion, a "Z" plasty in the smaller bronchus, as described by Holman and Hahn (1953), for dealing with this problem in blood vessels, has been of value in the laboratory.

SUMMARY

The indications for reparative surgery in dealing with lesions of the trachea in its cervical and thoracic parts, and of the main bronchi, has been discussed. Details of cases, illustrating the subject matter and also developmental surgical procedures carried out to investigate some controversial problems, have been included in the text.

I wish to thank members of the Chest Unit for permission to discuss the patients and for their help in the management of them.

Case 3 was operated upon by Mr. Douglas Robb assisted by the author.

I acknowledge with pleasure the skill of Dr. J. R. Hinds in making the outline drawings, the help of Dr. Chisholm McDowell with the manuscript, the industry of Miss Catherine Tibbles of the Central Medical Library, the painstaking photography of Mr. Burge, and the patience of Miss Kerkin in the typing of the manuscript.

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POSTURAL CYANOSIS AND ANGINA PECTORIS FOLLOWING PNEUMONECTOMY: RELIEF BY CLOSURE OF AN INTERATRIAL SEPTAL DEFECT

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THIS is a report of an unusual postpneumonectomy complication, the development of an interatrial right-to-left shunt. The story is even more unusual in that cyanosis and angina pectoris developed only when the patient was sitting or standing; recumbency brought relief. Before this abnormal communication was recognized and closed surgically, with almost complete alleviation of the patient's symptoms, a variety of clinical and laboratory observations, correct in themselves, had inspired some incorrect diagnoses. We believe that it will be useful to present not only the case report but also an account of our early hesitant and faulty diagnoses. Our difficulties are well described by John Hayward when he wrote, "For who is so deaf or so blind as he that willfully will neither hear nor see?"

CASE REPORT

The patient, a 60-year-old man, was admitted to the Hospital of the University of Pennsylvania on July 3, 1950, because of repeated episodes of hemoptysis during a 2-day period. He stated that he had been in good health except for several attacks of renal colic and an episode of epigastric pain fifteen years before that had been attributed to a duodenal ulcer. Chest x-rays, bronchoscopic examination, and microscopic study of the bronchial secretions failed to reveal the cause of the pulmonary bleeding. He was followed as an outpatient, however, with periodic physical examinations and chest x-rays until July, 1952, when a definite lesion was found by x-ray in the upper lobe of the right lung.

He was then admitted to the University Hospital for thoracotomy. At that time, he gave no history of dyspnea, chest pain, cyanosis, or ankle edema. On physical examination, no cyanosis was noted nor was there any clubbing of the fingers or toes. The blood pressure was 130/80. No cardiac murmurs were heard. The anteroposterior chest diameter was slightly increased, suggesting a minimal degree of emphysema. Fluoroscopy of the chest revealed no cardiac enlargement. An electrocardiogram was within normal limits. Numerous hemoglobin determinations ranged between 14.5 and 16.2 Gm. The highest red blood cell count was 4.6 million. Shortly after admission, a thoracotomy was performed. A 3 cm. mass in the right upper lobe was found, which proved on frozen section to be a squamous-cell carcinoma. A right pneumonectomy was done. No evidence of metastasis was found in twelve hilar lymph nodes. The postoperative course was uneventful except that on the sixth day he noticed anterior chest pain; it was thought to be related to the incision. He was discharged on the fourteenth postoperative day.

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During the next fourteen months he was readmitted to the hospital five different times His chief complaint on each admission was dyspnea associated with epigastric pain, the latter was not relieved by food or alkali At first these symptoms appeared only during the day Later he noticed that the pain and dyspnea occurred only when he was sitting or standing, and disappeared completely when he was horizontal in bed Eventually, the severity of the symptoms had become so great that he voluntarily remained in bed most of the time

On the first readmission, one month after the lung resection, the physical examination had showed no changes beyond those connected with the shift to the right of the mediastinal structures and the usual hydrothorax following pneumonectomy No cyanosis was observed A gastrointestinal series was interpreted as indicative of an active duodenal ulcer In spite of the atypical pattern of the pain, his symptoms were thought to be due to the ulcer He was therefore discharged on a strict Sippy regimen

On the second readmission, two months later, it was thought that the pain and dyspnea, which had not been relieved by the Sippy regimen, might be related to a decrease in pulmonary reserve, resulting from pneumonectomy One observer at this time noted "a peculiar, blue color to his fingernails," but another of his physicians stated that "no cyanosis was present" Limited pulmonary function studies showed a vital capacity of 2,060 ml, an inspiratory capacity of 1,280 ml, expiratory reserve of 780 ml, maximal breathing capacity of 60 L per minute, and some degree of nonuniform gas distribution An ear oximeter* showed some increase in the arterial oxygen saturation following two minutes on a treadmill at two miles per hour During this exercise the patient developed severe dyspnea and chest pain Since the studies showed fairly good ventilatory function for a 60 year old man with one lung, it was thought that the reduced exercise tolerance might be due, at least in part, to cardiac insufficiency The diagnosis on discharge was dyspnea with 'a marked functional component" No explanation of the cyanosis noted by one observer was offered

On the third readmission, in January of 1953, the severity of the dyspnea and pain on standing or sitting made him stay in bed almost constantly, but the physical findings remained unchanged No cyanosis was observed by anyone Numerous studies were made (1) Gastrointestinal x rays and esophagoscopy revealed no evidence of hiatal hernia The old duodenal ulcer appeared unchanged from the previous examination (2) Bronchoscopic examination and chest x ray showed no signs of a malignant process nor any other possible cause for the pain (3) Electrocardiogram showed no evidence of myocardial abnormality Nitroglycerine did not relieve the pain (4) The use of pneumoperitoneum in an effort to increase the ventilatory efficiency did not relieve the symptoms (5) Oximetric studies following the inhalation of 100 per cent oxygen showed a 6 per cent rise in the arterial oxygen saturation, minimal exercise was associated with a 2 per cent fall in the arterial oxygen saturation These results were believed to be due to a decreased pulmonary reserve (6) A manometric analysis of arterial blood, drawn when the patient was recumbent, showed an oxygen saturation of 94 per cent On March 29, 1953, the patient was again discharged, this time without diagnosis Most of the observers felt that his main problem was psychiatric, in which opinion the psychiatrists concurred In retrospect, it becomes plain that no studies during this admission were directed toward the cardinal symptom in the patient's history, namely, that the pain and dyspnea were never present when he was recumbent

On his fourth readmission in August, 1953, one year after pneumonectomy, it was noted again that he was cyanotic The fingers showed early clubbing Hemoglobin determinations as high as 18 7 Gm were recorded, the hematocrit was 55 per cent Gastrointestinal x rays were again interpreted as showing an active duodenal ulcer A Sippy regimen was once more prescribed, and the patient was discharged

The fifth and last readmission was on Nov 24, 1953 Again, the history of dyspnea and pain, except when he was lying flat, was unchanged Some observers at this time

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*The oximeter used was a Millikan type which records *changes* in oxygen saturation with reasonable accuracy but does not measure *absolute* values for saturation unless first set to agree with values obtained by direct measurement on art [illegible]mples believed that he was cyanotic; others that he was not. The hemoglobin was recorded as 17.2 Gm., but otherwise the basic laboratory studies were within normal limits. An electrocardiogram showed questionable evidence of "old posterior wall damage." Members of the ward staff were now aware of the relation of the patient's symptoms to his posture; nevertheless, studies continued to be done with the patient recumbent. Circulation times of 22 and 35 seconds were reported, all done with the patient lying flat in bed.

Pulmonary function studies were requested again but only screening procedures were considered necessary. Fortunately, three things now took place: First, the studies in the Pulmonary Function Section are done routinely with the patient in a semisitting position. Second, the patient's cyanosis in this position became obvious to all observers. Third, inhalation of oxygen increased the oximeter reading only 10 per cent and did not relieve the patient's cyanosis. It now became essential to determine the absolute values for arterial O_2 saturation by manometric determinations on arterial blood samples: while the patient was breathing air, the arterial O_2 saturation was 61 per cent; when breathing oxygen, it rose to only 66 per cent. Since, in the experience of the Pulmonary Function Section, the failure of inhalation of oxygen to increase saturation to 100 per cent should be explained only by the existence of a venous to arterial shunt,* they recommended that angiocardiograms and cardiac catheterization be done to determine whether this shunt was located in the lung or in the heart. Thus, in December of 1953, one year and five admissions after the patient's first complaint following pneumonectomy, the diagnosis of the right-to-left shunt was made.

Quickly, however, it was discarded because an angiocardiogram, done with the patient recumbent, showed only questionable evidence of a small left-to-right shunt at the auricular level. Final "proof" that there could be no venous to arterial shunt came when cardiac catheterization, done with the patient recumbent, showed an arterial saturation of 94 per cent. The Pulmonary Function Section, indeed, was suspected of having drawn and analyzed venous rather than arterial blood. Several days later, stung by this accusation, the Pulmonary Function Section again withdrew blood from the semireclining patient from a vessel connected to a mercury manometer that registered a blood pressure of 110 mm. Hg, i.e., a vessel that could be assumed with some confidence to be an artery. When the patient breathed air, the saturation was 65 per cent and when he breathed oxygen, the saturation increased to 78 per cent.

Discussion between members of the Cardiovascular and the Pulmonary Function Sections now became sufficiently heated to result in the performance of three really critical studies:

1. *Inhalation of low oxygen concentration.* With the patient recumbent and asymptomatic, the pain and dyspnea were reproduced by the inhalation of 10 per cent oxygen; the pain was relieved within two minutes after he breathed 100 per cent oxygen.

2. *Oximetric studies with the patient in various positions.* There was a marked rise in oxygen saturation when the patient lay down after standing. In addition, the arterial saturation was definitely and consistently higher when the patient lay on the right side rather than on the left.

3. *Circulation times, with the patient recumbent and at a 45-degree tilt.* An ear oximeter was used to follow the color changes following the injection of Evans blue dye through a catheter into the pulmonary artery, the right ventricle, and the right auricle. The results were as follows: At a 45-degree tilt, the circulation times were—pulmonary artery to ear, 13 seconds; right ventricle to ear, 14 seconds; right auricle to ear, 6 seconds. Recumbent, a very small amount of dye was detected at 6 seconds after the injection of the dye into the right auricle, while the majority of the dye reached the ear 10 seconds later.

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*In a study of more than 200 patients with anoxemia owing to a variety of causes, inhalation of 100 per cent oxygen always raised arterial oxygen saturation and dissolved oxygen content to maximal values unless a venous to arterial shunt (pulmonary hemangioma, atelectasis, or intercardiac right-to-left shunt) was present. A high [illegible] on of oxygen in the alveolar gas, effected by inhalation of [illegible] lways relie[illegible] mia caused by pulmonary disorders, whether due to hy[illegible] uneven [illegible] impaired diffusion.

Thus, the final diagnosis was made that, following pneumonectomy, a venous to arterial shunt at the level of the right atrium had developed, which was inconsequential when the patient was recumbent However, when the patient was erect the shunt increased in size and caused sufficient hypoxia to produce anginal type of pain

On Jan 13, 1954, a thoracotomy was performed On exploring the right atrium with the index finger inserted through the atrial appendage, an interatrial defect slightly larger than the finger was found The defect, which appeared to be a foramen ovale type, was located behind and slightly superior to the orifice of the superior vena cava By passing two silk sutures through the wall of the atrium, the valve of the foramen ovale, and the interatrial septum, it was possible to close the defect completely when the sutures were tied Postoperatively, the patient made an excellent recovery Now, twenty two months later, he is still acyanotic and ambulatory He feels a dull epigastric sensation, but that is far different from the severe anginal pain about which he had previously complained The arterial oxygen saturation, while breathing air, is 97 per cent in any posture, whether measured by the Pulmonary Function or the Cardiovascular Sections, and, while breathing 100 per cent oxygen, the arterial oxygen saturation and the dissolved oxygen reach maximal values

DISCUSSION

Recently, Wright and his associates[1] reported the case of a 31-year old man in whom "orthostatic" dyspnea and cyanosis appeared subsequent to a traumatic injury of the chest Catheterization findings and direct palpation of the right atrium at thoracotomy led them to the conclusion that their patient had Ebstein's malformation, the atrial septal defect was closed, and the symptoms disappeared Although our patient's somewhat similar symptoms also followed traumatic injury of the chest, though of a different type (pneumonectomy), it was not possible, either on the basis of catheterization findings or by direct palpation of the atrium at the time of surgery, to implicate Ebstein's malformation It is our conclusion that the venous to arterial shunt in our patient probably occurred because of a simple foramen ovale type of defect

Cyanosis occurring only in the sitting or erect position in patients with intracardiac shunts may be caused by several mechanisms

1 *A change in the pressure gradient sufficient to produce a right to left shunt or to increase the magnitude of an existing shunt* This physiologic state has been reported by Hamilton[2] in a patient with tetralogy of Fallot resulting from a marked drop in systemic arterial pressure It might also occur as the result of an increase in right heart pressures owing to increased resistance to flow through the pulmonary vascular bed It was not possible to demonstrate that either of these conditions was present in our patient The systemic arterial pressure did not change appreciably when he was in the erect position, nor could any elevation of right heart pressures be detected when he changed from the recumbent to a 45 degree semisitting position It is possible, however, that a pressure gradient developed in our patient when he was in the erect position because of the usual shift of the mediastinal structures after pneumonectomy which, in this patient, led to a change in the relative positions of the two atria Evidence in support of this possibility is that a higher degree of arterial saturation was found when he was in a right lateral position than when in a left lateral position Indeed, in the left lateral position, a pressure gradient favorable to the shunting of blood from right to left may well have developed on the basis of hydrostatic factors alone

believed that he was cyanotic; others that he was not. The hemoglobin was recorded as 17.2 Gm., but otherwise the basic laboratory studies were within normal limits. An electrocardiogram showed questionable evidence of "old posterior wall damage." Members of the ward staff were now aware of the relation of the patient's symptoms to his posture; nevertheless, studies continued to be done with the patient recumbent. Circulation times of 22 and 35 seconds were reported, all done with the patient lying flat in bed.

Pulmonary function studies were requested again but only screening procedures were considered necessary. Fortunately, three things now took place: First, the studies in the Pulmonary Function Section are done routinely with the patient in a semisitting position. Second, the patient's cyanosis in this position became obvious to all observers. Third, inhalation of oxygen increased the oximeter reading only 10 per cent and did not relieve the patient's cyanosis. It now became essential to determine the absolute values for arterial O_2 saturation by manometric determinations on arterial blood samples: while the patient was breathing air, the arterial O_2 saturation was 61 per cent; when breathing oxygen, it rose to only 66 per cent. Since, in the experience of the Pulmonary Function Section, the failure of inhalation of oxygen to increase saturation to 100 per cent should be explained only by the existence of a venous to arterial shunt,* they recommended that angiocardiograms and cardiac catheterization be done to determine whether this shunt was located in the lung or in the heart. Thus, in December of 1953, one year and five admissions after the patient's first complaint following pneumonectomy, the diagnosis of the right-to-left shunt was made.

Quickly, however, it was discarded because an angiocardiogram, done with the patient recumbent, showed only questionable evidence of a small left-to-right shunt at the auricular level. Final "proof" that there could be no venous to arterial shunt came when cardiac catheterization, done with the patient recumbent, showed an arterial saturation of 94 per cent. The Pulmonary Function Section, indeed, was suspected of having drawn and analyzed venous rather than arterial blood. Several days later, stung by this accusation, the Pulmonary Function Section again withdrew blood from the semireclining patient from a vessel connected to a mercury manometer that registered a blood pressure of 110 mm. Hg, i.e., a vessel that could be assumed with some confidence to be an artery. When the patient breathed air, the saturation was 65 per cent and when he breathed oxygen, the saturation increased to 78 per cent.

Discussion between members of the Cardiovascular and the Pulmonary Function Sections now became sufficiently heated to result in the performance of three really critical studies:

1. *Inhalation of low oxygen concentration.* With the patient recumbent and asymptomatic, the pain and dyspnea were reproduced by the inhalation of 10 per cent oxygen; the pain was relieved within two minutes after he breathed 100 per cent oxygen.

2. *Oximetric studies with the patient in various positions.* There was a marked rise in oxygen saturation when the patient lay down after standing. In addition, the arterial saturation was definitely and consistently higher when the patient lay on the right side rather than on the left.

3. *Circulation times, with the patient recumbent and at a 45-degree tilt.* An ear oximeter was used to follow the color changes following the injection of Evans blue dye through a catheter into the pulmonary artery, the right ventricle, and the right auricle. The results were as follows: At a 45-degree tilt, the circulation times were—pulmonary artery to ear, 13 seconds; right ventricle to ear, 14 seconds; right auricle to ear, 6 seconds. Recumbent, a very small amount of dye was detected at 6 seconds after the injection of the dye into the right auricle, while the majority of the dye reached the ear 10 seconds later.

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*In a study of more than 200 patients with anoxemia owing to a variety of causes, inhalation of 100 per cent oxygen always raised arterial oxygen saturation and dissolved oxygen content to maximal values unless a venous to arterial shunt (pulmonary hemangioma, atelectasis, or intercardiac right-to-left shunt) was present. A high concentration of oxygen in the alveolar gas, effected by inhalation of oxygen, always relieved the anoxemia caused by pulmonary disorders, whether due to hypoventilation, uneven distribution, or impaired diffusion.

Thus, the final diagnosis was made that, following pneumonectomy, a venous to arterial shunt at the level of the right atrium had developed, which was inconsequential when the patient was recumbent. However, when the patient was erect the shunt increased in size and caused sufficient hypoxia to produce anginal type of pain.

On Jan. 13, 1954, a thoracotomy was performed. On exploring the right atrium with the index finger inserted through the atrial appendage, an interatrial defect slightly larger than the finger was found. The defect, which appeared to be a foramen ovale type, was located behind and slightly superior to the orifice of the superior vena cava. By passing two silk sutures through the wall of the atrium, the valve of the foramen ovale, and the interatrial septum, it was possible to close the defect completely when the sutures were tied. Postoperatively, the patient made an excellent recovery. Now, twenty-two months later, he is still acyanotic and ambulatory. He feels a dull epigastric sensation, but that is far different from the severe anginal pain about which he had previously complained. The arterial oxygen saturation, while breathing air, is 97 per cent in any posture, whether measured by the Pulmonary Function or the Cardiovascular Sections, and, while breathing 100 per cent oxygen, the arterial oxygen saturation and the dissolved oxygen reach maximal values.

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Recently, Wright and his associates[1] reported the case of a 31-year-old man in whom "orthostatic" dyspnea and cyanosis appeared subsequent to a traumatic injury of the chest. Catheterization findings and direct palpation of the right atrium at thoracotomy led them to the conclusion that their patient had Ebstein's malformation, the atrial septal defect was closed, and the symptoms disappeared. Although our patient's somewhat similar symptoms also followed traumatic injury of the chest, though of a different type (pneumonectomy), it was not possible, either on the basis of catheterization findings or by direct palpation of the atrium at the time of surgery, to implicate Ebstein's malformation. It is our conclusion that the venous to arterial shunt in our patient probably occurred because of a simple foramen ovale type of defect.

Cyanosis occurring only in the sitting or erect position in patients with intracardiac shunts may be caused by several mechanisms:

1. *A change in the pressure gradient sufficient to produce a right to left shunt or to increase the magnitude of an existing shunt.* This physiologic state has been reported by Hamilton[2] in a patient with tetralogy of Fallot resulting from a marked drop in systemic arterial pressure. It might also occur as the result of an increase in right heart pressures owing to increased resistance to flow through the pulmonary vascular bed. It was not possible to demonstrate that either of these conditions was present in our patient. The systemic arterial pressure did not change appreciably when he was in the erect position, nor could any elevation of right heart pressures be detected when he changed from the recumbent to a 45 degree semisitting position. It is possible, however, that a pressure gradient developed in our patient when he was in the erect position because of the usual shift of the mediastinal structures after pneumonectomy which, in this patient, led to a change in the relative positions of the two atria. Evidence in support of this possibility is that a higher degree of arterial saturation was found when he was in a right lateral position than when in a left lateral position. Indeed, in the left lateral position, a pressure gradient favorable to the shunting of blood from right to left may well have developed on the basis of hydrostatic factors alone.

2. *A decreased venous oxygen saturation.* If such a condition existed, no increase in the volume flow through the shunt need be postulated, since the increased cyanosis could be due merely to the mixture of arterial blood with venous blood of greater unsaturation flowing in constant amounts through the shunt. It has been shown recently[3] that this mechanism may be the cause of the increased cyanosis seen in patients with tetralogy of Fallot when in an erect position. In the patient reported by Wright and colleagues,[1] the size of the shunt and the degree of cyanosis were not closely related. In our patient, however, the ear oximeter studies using Evans blue dye strongly suggest that most of the cyanosis was due to an increase in the actual degree of the venous to arterial shunt whenever he sat up.

The failure of all but one of our patient's physicians to detect the early signs of cyanosis raises the following points: (1) The clinical diagnosis of arterial anoxemia by visual observation of cyanosis is uncertain, for the ability to recognize blueness varies greatly,[4] (2) a well-calibrated, absolute reading oximeter may be required to detect anoxemia unless an arterial blood sample is drawn and analyzed, and (3) incomplete pulmonary function studies may be misleading; therefore, a complete arterial blood gas analysis should be done whenever screening procedures give a questionable diagnosis.

In retrospect, it is hard to understand why so many of us for so long paid no attention to the patient's history of pain and dyspnea in connection with his position. This reluctance to believe what we heard and saw was due to our desire to accept an ordinary explanation as the basis of the patient's symptoms and a certain lack of imagination with which we might have postulated a complication of this type resulting from pneumonectomy.

SUMMARY

1. A case is reported in which a 60-year-old male patient developed a venous-arterial shunt through an interatrial septal defect following pneumonectomy performed because of carcinoma of the right lung.

2. The changes associated with the atrial septal defect resulted in dyspnea, epigastric pain, and cyanosis in the sitting and standing positions only; they disappeared on recumbency.

3. Hypoxia was found to occur only in the sitting or standing position and was responsible for the dyspnea, cyanosis, and anginal pain.

4. The atrial defect was surgically closed with almost complete alleviation of the patient's symptoms.

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RESECTION AND ORLON GRAFT OF MULTIPLE AORTIC ANEURYSMS DUE TO TRAUMA

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TWO major problems arise from the cross-clamping of the thoracic aorta during resection and graft replacement. They are a rapid dilatation and failure of the left ventricle, and ischemic damage to distal organ systems

Hypothermia is a means by which the cardiac output can be reduced and the distal refrigerated tissue has an increased tolerance to ischemia [1]

DeBakey and Cooley (1954)[2] and Julian and associates (1953)[3] have reported two successful resections and homografting of traumatic thoracic aneurysms under hypothermia. An additional successful case of traumatic multiple aneurysms of the thoracic aorta treated by resection and orlon graft with hypothermia is presented.

CASE REPORT

A 31-year old white man was injured by a land mine explosion in 1943 during World War II. He suffered severe contusion of the left chest without any external wounds and was hospitalized for eight months. Since discharge from the service he has complained of fatigue, weakness, exertional dyspnea, and left chest pain radiating posteriorly between the shoulders These symptoms increased in severity during the last year to such an extent that he sought medical attention Physical examination was negative except for a diminished radial pulse in the left arm The blood pressure was 110 systolic and 70 diastolic mm. Hg. The serology was negative. Complete blood count, urinalysis, and blood chemistry studies were within normal limits An electrocardiogram was normal

Roentgenologic and fluoroscopic findings confirmed the diagnosis of an aneurysm of the descending arch and thoracic aorta

Operation: On Sept. 9, 1955, thoracotomy was done with endotracheal anesthesia Anesthetic agents consisted of Pentothal sodium, oxygen ether, and general hypothermia to 28° C Two aneurysms were present The superior one arose 2 cm below the origin of the left subclavian artery and extended posteriorly into the vertebral gutter and measured 6 by 6 cm Immediately below this aneurysm the aorta was of normal caliber for a distance of 1 5 cm Another aneurysm arose below this level and extended medially into the mediastinum and measured 4 by 4 cm This medial aneurysm compressed the left main stem bronchus (Fig 1). The aorta above and below the aneurysm was normal

The distal thoracic arch of the aorta and the left subclavian artery were occluded with a DeBakey clamp. The distal descending aorta was then cross clamped. The rectal temperature was 28° C when the aorta was cross clamped The blood pressure prior to occlusion was 60 systolic and 40 diastolic mm Hg and rose to a level of 120 systolic and 60 diastolic mm. Hg during the 50 minutes of complete occlusion The multiple aneurysms were excised and the segmental intercostal arteries were ligated as they were encountered A seamless orlon prosthetic graft 12 cm long was sutured into the aortic defect (Fig. 2). A continuous No. 4 0 black arterial silk suture was used The distal clamp was removed first, allowing the orlon graft to distend and fill the mesh of the orlon with fibrin

The proximal occluding aortic clamp was gradually released over a 25 minute period. The blood pressure at the end of this time was 60 systolic and 40 diastolic mm. Hg. One thousand cubic centimeters of whole blood was given for replacement. The lungs were

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expanded and catheter chest drainage instituted. The patient was rewarmed to 96° F. and returned to the recovery room. Blood pressure at this time was 120 systolic and 60 diastolic mm. Hg.

Pathology: Sections of the excised aneurysms showed hyalinization, calcification, and fragmentation of the elastic fibers. Many areas of the aneurysms were thin and elastic fibers were absent.

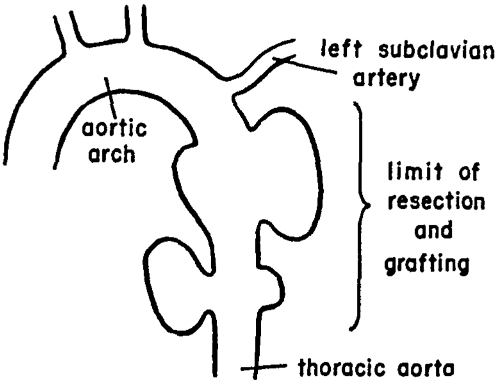

Fig. 1.—Diagram of multiple thoracic aneurysms due to trauma.

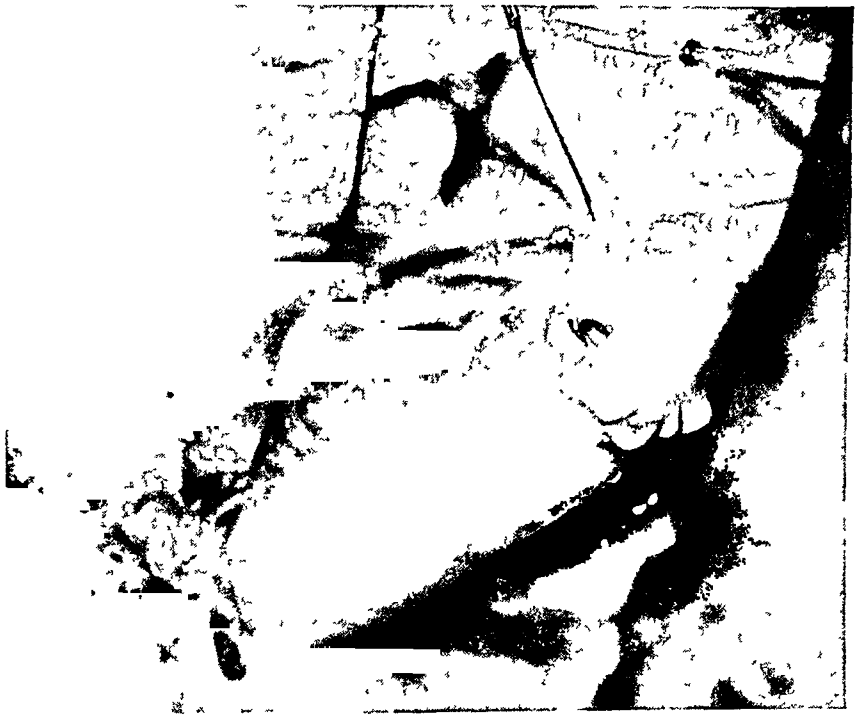

Fig. 2.—Surgical defect of descending thoracic aorta spanned with a seamless orlon graft

The postoperative course was uneventful and the patient was discharged on the tenth postoperative day to another hospital to convalesce for an additional two weeks. There were no cardiac or neurological complications.

DISCUSSION

Lam and Aram (1951)[4] reported the homografting of a syphilitic thoracic aneurysm. The aneurysmal sac was left in place and the patient died in three months from a mediastinal abscess with secondary hemorrhage.

Brock and Graham (1952)[5] successfully resected and homografted an aneurysm associated with coarctation. The presence of adequate collateral circulation in coarctation markedly differentiates the effect of thoracic aorta occlusion from that of an aneurysm.

DeBakey and Cooley (1953)[6] and Gwathmey and Thompson (1955)[7] successfully resected and replaced a fusiform arteriosclerotic thoracic aneurysm with a homograft. These two operations were done without hypothermia One cannot predict preoperatively the reserve of the heart to withstand the work load incident to aortic occlusion or ischemic damage to distal organ systems.

In order to circumvent the complications of acute aortic cross-clamping, intraluminal, or external shunts along with partial venous inflow occlusion have been done.[8] Hypothermia seems a more simple method. The depth of hypothermia does not have to be extreme. A range of 28° C. to 30° C. protects the heart against overloading and distal organ systems against ischemia.

SUMMARY

The successful repair of multiple traumatic thoracic aneurysms of the thoracic aorta is reported Under hypothermia, a seamless orlon graft was used to graft the thoracic defect.

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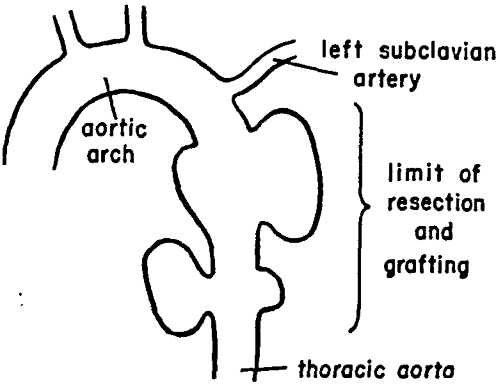

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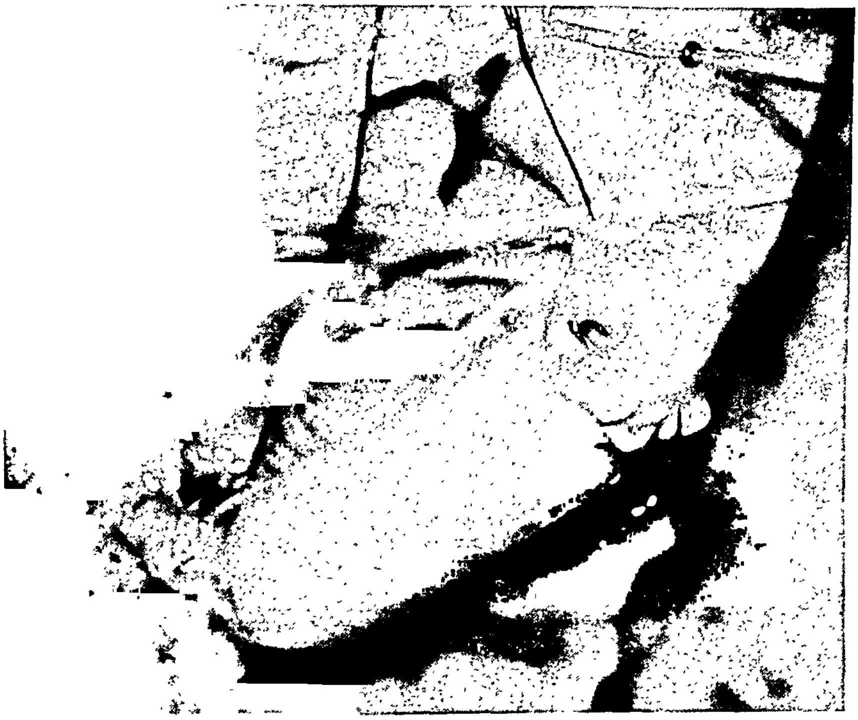

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LUNG ABSCESS IN INDIA

BINDRA BAN, M.B.B.S.
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MUCH of the knowledge regarding the etiological factors of lung abscess has been derived from the experimental work of Brock (1942) and Wig (1951). Allen (1928) has contributed a great deal to the understanding of the pathology of lung abscess.

The advent of sulfonamides and antibiotics has changed the outlook in this malady. It appears that the time has come when the opinion expressed by Smith (1948), Klepser and Davis (1952), and Brock (1952) should be reconsidered in the light of the experience gained in recent years. After a critical study of the papers of Jewett and Dimond (1950), Metras and Charpin (1954), Fox and co-workers (1954), and Gittens and Mihaly (1954), the much advocated surgical procedures even in acute lung abscesses seem to be a little out of place. Acute lung abscesses respond easily to the antibiotics.

In the present communication an attempt will be made to discuss the role of antibiotics in the management of lung abscess.

METHODS, MATERIAL, AND RESULTS

The present study includes an analysis of 60 cases of lung abscess, 31 of which were studied at Jaya Aroyga Hospital, Gwalior, from March, 1950, to April, 1953, while 29 cases were studied at the tuberculosis clinic, Delhi, from April, 1953, to August, 1955.

Only those cases have been included in which a specific cause could not be found. Lung abscesses secondary to neoplasm, amebiosis, bronchiectasis, and foreign body have been excluded.

Sex: Out of 60 patients, 52 were males, and 8 females.

Age: Table I shows the age distribution.

TABLE I. THE AGE DISTRIBUTION

AGE (YEARS)	NUMBER OF CASES
Under 10	3
11-20	8
21-30	11
31-40	11
41-50	16
51-60	11

Etiology: No case was encountered following dental extraction, operations on the respiratory tract, or as a postoperative complication. In 22 cases,

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dental sepsis was a prominent feature, in another 15 cases, there were coryza and catarrh of the upper respiratory passages immediately preceding the lung abscess. In 23 cases, no definite etiological factor could be found.

The lobar distribution is presented in Table II.

TABLE II. THE LOBAR DISTRIBUTION

LOCATION	NUMBER OF CASES
Right upper lobe	20
Right middle lobe	5
Right lower lobe	18
Left upper lobe	9
Left lower lobe	8

In only 20 cases, in addition to posteroanterior views, lateral skiagrams of the chest were taken also to find the segmental distribution. The results are shown in Table III.

TABLE III. THE SEGMENTAL DISTRIBUTION

SEGMENTS	RIGHT SIDE	LEFT SIDE
Upper Lobe		
Anterior	–	2
Posterior	5	–
Both segments	1	–
Lower Lobe		
Apical	6	3
Anterior basal	1	–
Posterior basal	–	1
Middle lobe	1	–

The relation of the duration of the disease and the effect of therapy is presented in Table IV.

TABLE IV. THE EFFECT OF THERAPY AND DURATION OF THE DISEASE

DURATION	NUMBER OF PATIENTS	DIED	CHRONIC	CURED
Six weeks	41	3	5	33
Over six weeks	19	–	11	8

In the evaluation, the patients who have been treated with antibiotics and have been followed for at least three months have been included. The results are tabulated in Table V. All patients received supportive measures such as proper postural drainage and necessary expectorants.

TABLE V. EFFECT OF TREATMENT

GROUPS	NUMBER OF CASES	DIED	CHRONIC	CURED
Group 1				
Penicillin and sulfonamides	49	3	11 – 10* – 8†	17
Group 2				
Penicillin and deep x rays	10*	–	3	7
Group 3				
Penicillin, high doses	19 (11 + 8)†	–	2 – 6‡	11
Group 4				
Tetracycline	6‡	–	–	5
	60	3	1[illegible]	41

The symbols *, † and ‡ represent the number of cases – another when one line of therapy failed, each pair of symbols

GROUP 1. Forty-nine patients were treated with penicillin, 2 to 4 lacs* daily, in divided doses for a total of 40 to 60 lacs and, in addition, sulfadiazine, about 30 Gm., was administered also. After about three weeks, clinical and roentgenologic studies were undertaken to evaluate the results. Seventeen patients were completely cured clinically and roentgenologically, while in 11 there was no improvement, and another 18 showed clinical improvement without any significant change in roentgenologic shadows. This represents a cure rate of about 34 per cent. Bronchographic examination was carried out in 2 cases. In 1, there was classical saccular bronchiectasis while in the other there was a minor degree of cylindrical bronchiectasis.

Fig. 1.—A skiagram of chest, posteroanterior view (K. C., June 6, 1953), which shows a cavity with fluid level 5 by 4 cm. surrounded by homogeneous opacity.

Illustrative case: K. C., 1738/55, a 24-year-old man, reported on June 16, 1953. The patient had had a cold and coryza with rhinitis about three weeks previously. About 2 weeks afterward, he had pain in the right chest and one week later noted fever and cough with profuse foul-smelling expectoration. The past history was not relevant. His occupation was cleaner of petrol trucks. At least twice a week, he had to empty the tank by siphoning the remaining petrol from it. A skiagram of the chest made June 15, 1953 (Fig. 1) showed a cavity with a fluid level of 5 by 4 cm. surrounded by a homogeneous opacity which occupied the posterior segment of the right upper lobe. He was given 60 lacs of procaine penicillin, as 4 lacs daily, which gave him complete clinical cure, but did not clear a 15 per cent loss of radiolucency. Over a follow-up period of two years he has had no complaints. Tomograms made on July 26, 1955, showed small cystlike cavities in the affected segment. Bronchograms, made on Sept. 4, 1955 (Fig. 2), revealed saccular and cystic ectasis of the posterior segment of the upper lobe and apical segment of the right lower lobe.

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*A lac represents 100,000 units.

Comments: Probable pathogenesis in this case appears to be infection of the upper respiratory tract and, at the same time, inhalation of the petroleum. The infected material along with the petroleum produced a bronchial embolism leading to an abscess formation. The abscess did not limit itself to the segmental barrier as shown by the cylindrical ectasis of the apical segment of the lower lobe. Further, this extensive bronchiectasis did not produce any signs and symptoms for over two years.

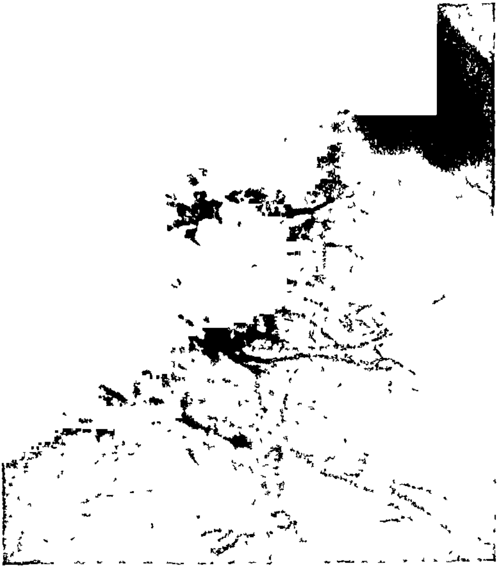

Fig 2—A bronchogram, right lateral view (K C, Sept. 4, 1955), which shows saccular and cystic bronchiestasis

Group 2. As chest surgery was not available in J. A. Hospital, Gwalior, it was decided that the patients who did not show a satisfactory response to penicillin after three weeks should be submitted to a course of deep roentgen ray irradiation to the chest with the idea of producing fibrosis. It must be confessed that this was an empirical therapy. In this group, penicillin was continued for another two weeks and the chest was exposed to deep x-rays to a total of 1,000 gamma units as 100 units daily, alternately on the back and front of the chest. After two weeks, the cases were again reviewed and if the cavity had closed [*though slight (10 per cent) loss of radiolucency might persist*] with no signs and symptoms, the case was labeled as cured. Hematologic study revealed no adverse effects. Ten patients from Group 1, 1 chronic, and 9 relieved, were submitted to this therapy. There was no change in the chronic lung abscess, but out of the 9 relieved patients, 7 were cured completely

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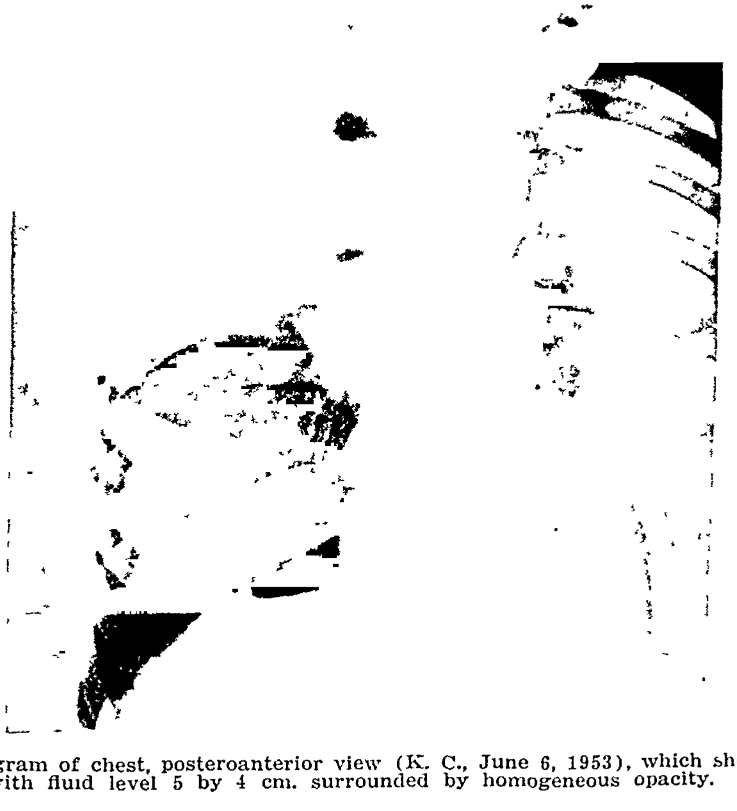

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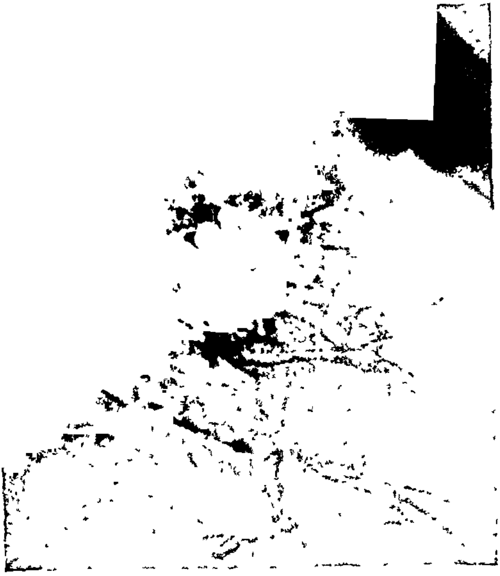

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Fig 3.—A skiagram of chest (M. R, July 5, 1952) which shows a cavity in the right lower lobe.

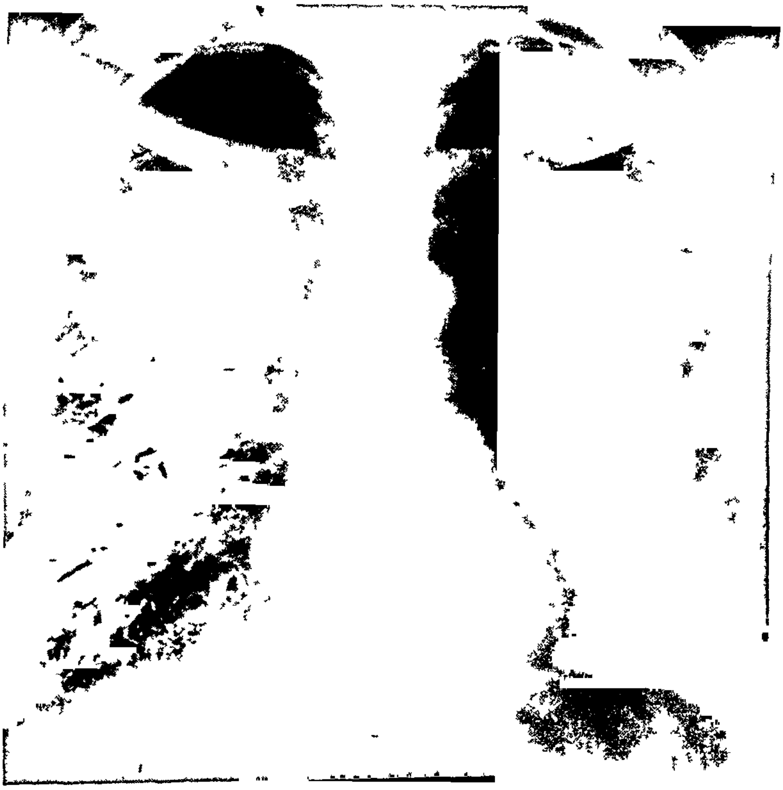

Fig 4—Bronchogram (M R, Sept 17, 1952). The cavity has disappeared but the contrast medium has not entered the diseased area.

according to the above-mentioned standard. Out of these 7 patients, 3 were submitted to bronchography and in all 3 the contrast medium did not enter the diseased area.

Illustrative case. A man 45-years-old, was admitted to J. A. Hospital, Gwalior, on June 20, 1952, *with a history of pyrexia, cough with expectoration, and pain in the right* side of the chest of six weeks' duration. Sputum on direct smear and concentration was negative for tubercle bacilli. Roentgenogram of the chest (July 5, 1952; Fig. 3), showed a cavity with a surrounding area of consolidation. He was given 60 lacs of penicillin with 30 Gm. of sulfadiazine. The clinical condition improved but a skiagram of the chest made July 28, 1952, showed no change. He was given another 30 lacs of penicillin and a course of deep roentgen rays. Bronchography (Fig. 4; Sept. 17, 1952) revealed that the cavity had disappeared, and only a slight haziness persisted. The contrast medium did not enter the diseased area.

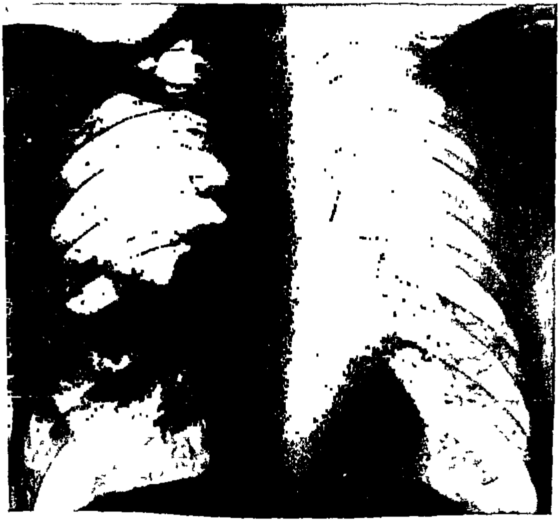

Fig. 5.—A skiagram of the chest, posteroanterior view (N. L., Nov. 26, 1954), shows a cavity 6 by 3.5 cm. in the right lower lobe

Group 3. With past experience and newer concepts it was felt that the dosage of penicillin was very low. It was decided that at least 10 to 20 lacs of penicillin should be given daily. Nineteen cases were submitted to this therapy, 8 of which had already received 40 to 60 lacs of penicillin without much roentgenologic change. Of these, 11 were completely cured, while 8 showed only clinical improvement.

Illustrative Cases.—

Case 1.—K. L., 931/55, a 30 year-old man, reported with a two-week history of fever and cough with profuse foul smelling expectoration. He had moderate hemoptysis. A skiagram of the chest made May 14, 1955, showed a cavity 8 by 5.6 cm. in the posterior

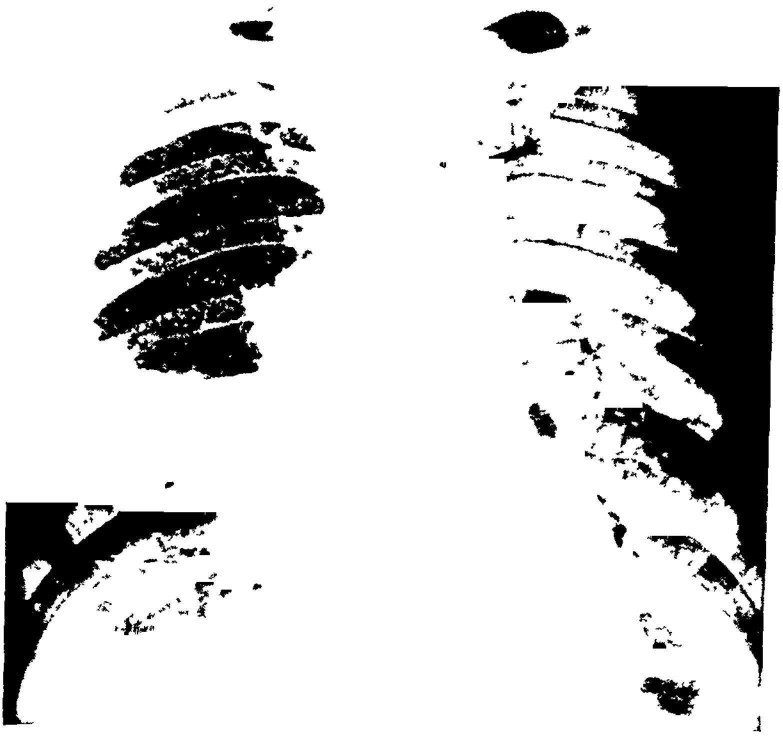

Fig. 6.—A skiagram of the chest, posteroanterior view (N. I., April 6, 1955), shows a homogeneous opacity at the site of cavity, probably an inspissated cavity.

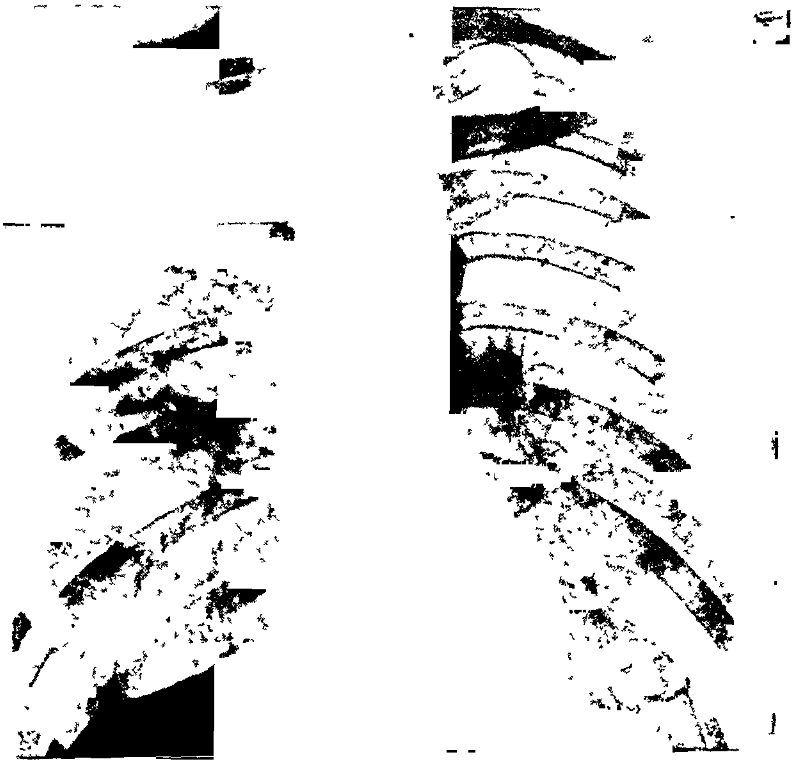

Fig. 7.—A skiagram of the chest, posteroanterior view (N. I., June 30, 1955), reveals a spill-over abscess, right upper lobe. The closed inspissated cavity has been replaced by small cystic shadows.

segment of the left lower lobe He received 300 lacs of penicillin during a one month period. Bronchograms made on Aug 24, 1955, showed two cystlike cavities in the posterior basal segment revealing that two bronchi were communicating with the abscess cavity.

Case 2—N. L., 3346/54, a 50 year old man, reported on Nov. 22, 1954, with a history of three weeks of fever and cough with profuse foul smelling expectoration. Past history revealed that he had frequent bouts of respiratory infection following an attack of cold and coryza. A skiagram make on Nov. 26, 1954 (Fig 5), revealed a cavity 6 by 3 5 cm. in the apical segment of right lower lobe. He was given 100 lacs of penicillin for a period *of ten days, with complete clinical cure but the cavity persisted. The patient discontinued* the treatment and reported again on April 6, 1955, and a skiagram of the chest revealed a homogeneous opacity (Fig. 6), probably an inspissated cavity. Bronchoscopy at this stage revealed that the right bronchus was full of thick secretion and there was some distortion of the bronchial tree. Congestion and swelling of the mucosa with some circumferential stenosis was also present. The apical segment of the lower lobe was completely occluded Again, the patient disappeared and a checkup on June 30, 1955 (Fig. 7), re*vealed a spill over abscess in the right upper zone, the inspissated cavity had been replaced* by a small cystlike cavity. The patient migrated to Pakistan at this stage.

Comment: This patient had little radiologic improvement after 100 lacs of penicillin. At one stage, the obstruction was complete in the bronchus due to endobronchial disease and plugging by the thick purulent material leading to the closed inspissated cavity. When the obstruction was relieved, the inspissated cavity was replaced by small cystlike shadows, in addition, he had a spill-over abscess.

Bronchographic examination was carried out in 4 cases, in 2, there was saccular bronchiectasis, in the other 2, there was cylindrical residual dilatation of moderate degree of the affected bronchi.

Group 4 It was decided that patients not responding to penicillin should be given broad spectrum antibiotics. We tried about 10 Gm. of tetracycline in divided doses in 6 patients with acute lung abscess with definite cavities. All responded with complete clinical and radiologic cure. Two patients were submitted to bronchographic examination, in 1 a cystlike cavity still persists after one and one-half years, and in the other a minor degree of cylindrical bronchiectasis still persists.

Illustrative case: S K, 17/54, a 14 year old girl, reported with a three week history of fever and cough with profuse foul smelling expectoration. A previous skiagram of the chest made Feb 27, 1953, was *normal. A skiagram of the chest made Dec. 8, 1953 (Fig.* 8), showed a cavity 8 by 6 cm in the anterior segment of the left upper lobe with a sur*rounding consolidation* She was given 160 lacs of penicillin over a period of three weeks. The cough and expectoration disappeared but the fever still persisted at 100° F A skiagram of the chest Jan 2, 1954 (Fig 9), showed a cystlike shadow 5 5 by 7 cm. She was given 8 Gm of Aureomycin (Lederle), the fever came down to normal A skiagram made on Jan 16, 1954 (Fig 10), showed that the cyst had enlarged to 7.5 to 9 cm. A bronchogram made on Feb. 17, 1955 (Fig 11), showed a cystlike cavity with a minor degree of residual ectasis of the anterior segment of the left upper lobe and lingula

Comment: This case is interesting due to the enlargement of the cavity in January, 1954, due to the *presence of a check valve, i e, partial obstruction* and the bronchogram revealed a cystlike cavity with a minor degree of ectasis.

Bronchoscopic examination during the disease or clinical cure was carried out in 7 *cases.* In 3 patients where cavity was demonstrable radiologically,

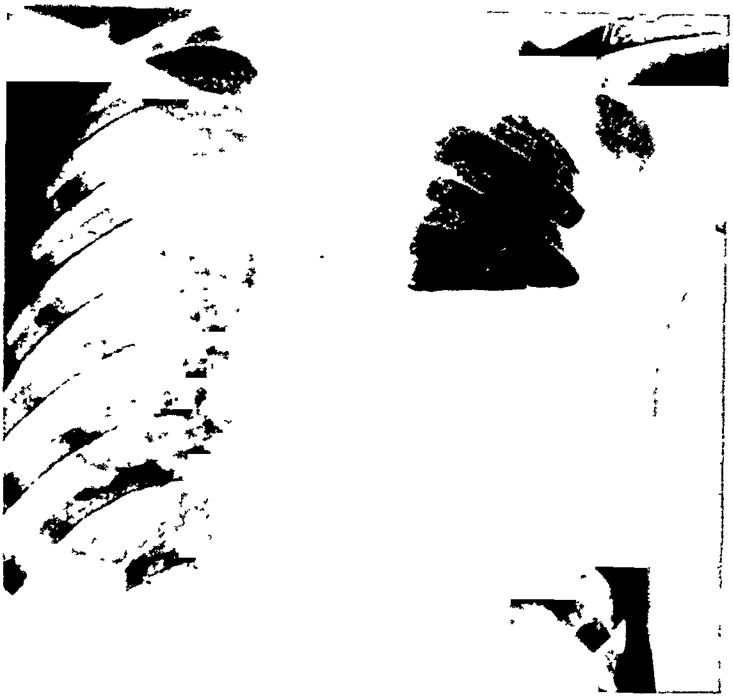

Fig. 8.—A skiagram of the chest (S. K., Dec. 8, 1953), shows a cavity 8 by 6 cm. with surrounding consolidation.

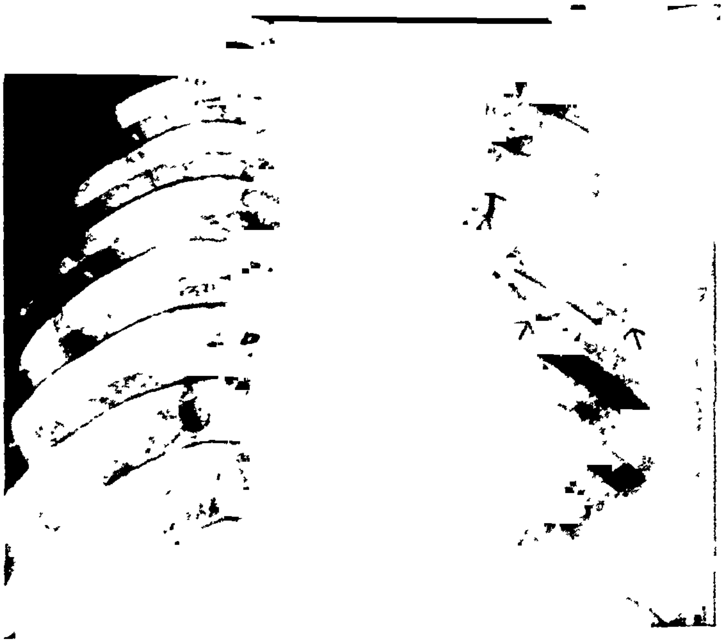

Fig. 9.—A skiagram (S. K., Jan. 2, 1954) showing a cystlike shadow 5.5 by 7 cm.

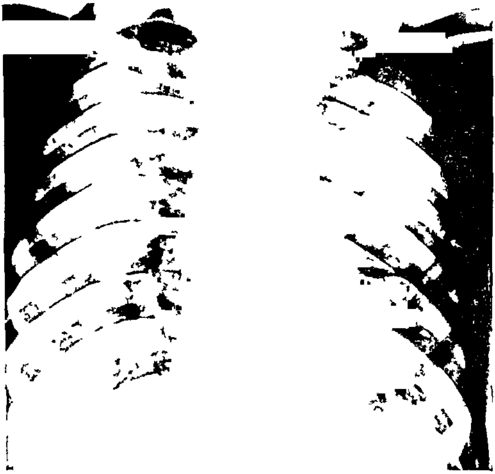

Fig 10 —A skiagram (S K Jan 16 1954) showing that the cyst has enlarged to 7 5 by 9 cm which indicates the presence of check valve phenomenon

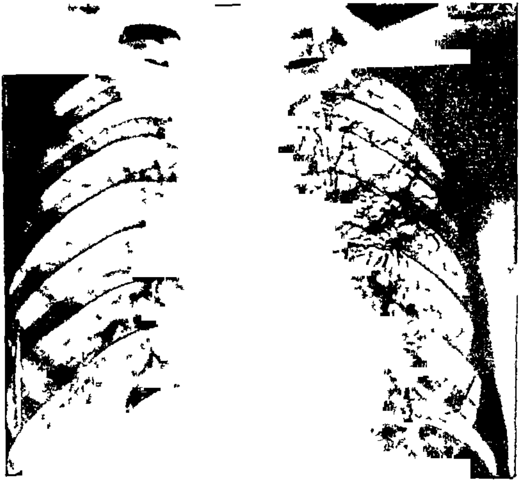

Fig 11 —A bronchogram (S K, Feb 17 1955) showing a small cystlike cavity with a minor degree of residual bronchiectasis

the bronchi were full of thick purulent material, the mucosa was inflamed and congested. There was some distortion of the bronchial tree. In 2 patients where there was complete clinical and radiologic cure there was 30 to 50 per cent bronchostenosis with distortion of the bronchial tree. In 2 patients no abnormality was detected.

DISCUSSION

The low incidence of lung abscesses in females in the present study, and also in the reports by Metras and Charpin (1954), Fox and associates (1954), and Gittens and Mihaly (1954), deserves serious consideration. No reasonable explanation is available. Lung abscess secondary to operative procedures has become comparatively much less. In the majority of cases, bronchial embolism takes place during a period when the defensive mechanisms are impaired by the upper or lower respiratory infections. An analysis of the records of this Clinic during the year 1953 revealed certain interesting facts: Of the number of patients suffering from pulmonary tuberculosis, 1,693 were men, and 1,533 were women; of those with other respiratory infections, 2,150 were men, and 808 were women.

Similar observations have been made in deaths accredited to chronic bronchitis by the Registrar General (1946) and Howell (1951), i.e., twice as common in males as compared to females. The incidence of acute pneumonias is 2 to 3 times greater in males than in females. It is difficult to determine whether males are specially susceptible to respiratory infections, or whether it is the occupational hazards, fatigue, and climatic factors which are responsible for this variation in incidence.*

In Brock's (1952) series, the incidence secondary to operative measures was very high. In the present series, however, no case was associated with any operative procedures. Wig (1951) could find only 1 case after tooth extraction in a series of 28 cases. In the present study, only cases where a cavity was seen at either roentgenologic or postmortem examination are included. Basal pneumonia, pneumonitis, or atelectasis is a very common complication of operative procedures. It is difficult to place in a water-tight compartment where a pneumonitis or atelectasis ends and suppuration begins so as to form a definite abscess cavity, as these are the different stages of the same inflammatory process. The appreciation of this postoperative complication and strict prophylactic measures such as frequent change of posture, breathing exercises, and measures not to inhibit the cough reflex must have contributed a great deal to the reduction of the incidence of lung abscess. The situation has further improved a great deal by the administration of penicillin, sulfonamides and other antibiotics as prophylactic measures.

With the meager data at our disposal regarding the bronchoscopic and bronchographic examination in clinically and radiologically cured patients with lung abscess, it appears that segmental bronchi take a prominent part in the suppurative process, and bronchial obstruction, either due to the purulent

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*It appears that the incidence of lung abscess runs parallel in females to the incidence of other respiratory infections.

material or the active inflammation of the bronchial mucosa, may lead to certain sequelae such as a minor degree of ectasis or the persistence of cystlike cavities In interpreting the bronchoscopic findings, the fact that the bronchi cannot be visualized beyond a particular distance must be kept in mind This ectasis depends on the degree of bronchial obstruction and the inflammatory and suppurative process present in the bronchial tree It has been shown that simple bronchial obstruction can lead to ectasis due to the retention and dilatation of the bronchi by the mucous Ciovatto and associates (1954), and Medlar (1955) from post mortem and resected specimens have brought out that if the bronchial pattern is distorted by extensive parenchymal scarring in non tuberculous conditions, the distention of the bronchi distal to the obstruction takes place by either retention of the secretions or the inflammatory products In about 80 per cent of the cases of lung abscess, there is bronchial embolism followed by segmental atelectasis, finally leading to suppuration It appears that residual ectasis following abscess depends on the duration of the block (by mucus, purulent material, and the mucosal inflammation and suppuration) and distortion of the bronchial pattern by the parenchymal scarring

The results are comparable to those of Smith (1948) in his 60 personal cases, Jewitt and Dimond (1950), Metras (1954), Fox and co workers (1954), and Gittens (1954), i e, about 60 7 per cent treated with antibiotics This high cure rate, in comparison with the previous work, is very striking Smith (1948) *in his collection of 1,498 cases from the literature found a cure rate of* 10 per cent Klepser and his colleagues (1952), and Brock (1952) recorded 40 8 per cent as the cure rate However, Smith (1948) collected the cases from the literature as far back as 1932, when the antibiotics were not known and the only treatment for lung abscess was to drain the pus either by postural drainage, expectorants, or surgical measures

The results have not been correlated with the duration of the abscess at the time of therapy Even with the advent of antibiotics and chemotherapeutic agents, the position with regard to chronic abscess has not changed as the antibiotic therapy may sterilize the cavity but does not help to close it The only remedy for such chronic lung abscess is surgery In this study, efforts have been made to correlate the prognosis with the duration of the symptoms It is difficult to place an abscess into an acute or chronic stage as the definition has been changing from time to time Neuhof (1940) labels abscesses acute within six weeks' duration, subacute from six to twelve weeks, and chronic after twelve weeks Sweet (1942) extends the period of the acute stage to four months, while Shaw (1942) extends it to six months Moore's (1942) view seems to be more rational, namely, that chronicity should be judged as revealed by clinical and radiologic study, time element cannot be the deciding factor as the present stage may be the exaggeration of the pre existing disease Table IV shows that there were 33 cures (80 per cent) out of 41 patients who were treated within six weeks of the onset of symptoms While in cases of more than six weeks' duration, there were 8 (40 per cent) cures out of 19 patients. It is not difficult to foresee that acute abscess of six weeks' duration, if treated with the proper antibiotic in proper doses, may not require any surgical measure.

The dosage schedule in the Group 1 and Group 2 as shown in Table V is very low as compared to the present-day conceptions. It is possible that if high doses of penicillin, namely, 10 lacs twice a day, are given in every case the cure rate may increase further.

The broad spectrum antibiotics should be tried in selected cases where the organisms are highly sensitive to Aureomycin, Terramycin, Achromycin or Ilotycin. In the present study, as already stated, all the 6 patients submitted to Aureomycin showed remarkable clinical and roentgenologic healing. Chandler and co-workers (1949) reported a patient with multiple lung abscess which responded to Aureomycin, while penicillin, sulfonamides, and streptomycin did not alter the course. Gruber and associates (1950), too, described a case of an infant with multiple cavities which showed an impressive response under a combination of streptomycin and Aureomycin with sterilization of the sputum and closure of the cavities. Gittens and Mihaly (1954) have also reported good results in acute lung abscesses treated with the tetracycline group of drugs. Barach and his colleagues (1952) in an excellent review are of the opinion that chronic pulmonary suppuration does not respond in a striking manner to Aureomycin.

It appears from the present study that in abscesses of recent origin a fair trial of antibiotics should be given and about 80 per cent of such abscesses will completely heal, clinically and radiologically. There is little disagreement with Brock's (1952) view that the expectant line of treatment should be continued so long as there is clinical and roentgenologic improvement. Large doses of penicillin and the tetracycline group of drugs should be tried in resistant cases.

SUMMARY

A study of 60 cases of lung abscess is presented. No case secondary to operative procedure was found. It appears that prophylactic use of antibiotics and other measures have reduced the incidence. The low incidence of lung abscess in females is a very remarkable feature. Perhaps it runs parallel to the low incidence of other respiratory infections like bronchitis and pneumonia in females. The residual bronchiectasis is usually symptomless and is due to the active part played by the bronchi in the pathologic process. With the use of antibiotics in large doses in acute lung abscess, a cure rate of about 80 per cent can be achieved.

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ERYTHROMYCIN AS PROPHYLAXIS IN PULMONARY RESECTION

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PARENTERAL use of various drugs as prophylactic agents against postsurgical infections has been practiced since effective chemotherapeutic agents became available.[1,2] Because empyema constitutes one of the more serious complications after pulmonary resection, often resulting in a high mortality rate or prolonged course of hospitalization for the patient, there is a continuing necessity to seek a more effective prophylactic agent. In recent years, antibiotics have become decreasingly effective in preventing this complication due to increasing bacterial resistance to the drugs. This has been evident especially in the case of penicillin-resistant staphylococci.[3] Also, there is no certainty that the various drugs are distributed in adequate concentration after parenteral administration in the pleural space especially in cases of this type where need for the drug is greatest. This is true particularly with penicillin on which detailed studies have been made.[4]

With the discovery of erythromycin,[†] the problem of penicillin-resistant bacteria has become easier to manage because of the drug's high activity against the microorganisms[5-7] most often implicated in empyema. Furthermore, the lack of toxicity and the demonstrated accumulation of the drug when given in multiple intrapleural[8,9] doses make this antibiotic a practical one to use as a prophylactic agent in thoracic surgery. Thus, the purpose of this investigation is to determine if erythromycin would provide adequate antibiotic coverage in patients undergoing pulmonary resection.

MATERIALS AND METHODS

Thirty patients undergoing lung resection in this institution served as subjects for this study. All antibiotics were discontinued three days prior to the start of the experiments and only erythromycin was administered postoperatively. This series of patients was divided into two groups depending on the absence or presence of intrapleural catheter drainage after surgery, namely,

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[†] Erythromycin used was supplied by Abbott Laboratories, North Chicago, Ill.

pneumonectomy and partial resection cases, respectively In the pneumonectomy group, there were 18 patients, 12 of whom were studied after receiving a single injection of erythromycin, of these 12, 8 patients had received 250 mg and 4 had received 400 mg of erythromycin Patients in this group were given the drug intrapleurally immediately after closure of the chest, through the needle used for measurement of intrapleural pressure In all cases, the drug administered intrapleurally was the lactobionate salt of erythromycin in 1 per cent solution The remaining 6 patients in this group were given an initial instillation, with subsequent injections made by the barbotage method in order to avoid painful intrapleural reaction[9] To 12 patients, who comprised the partial resection group, 250 mg of erythromycin was given after closure of the chest through the anterior catheter inserted at the level of the second anterior interspace while a second catheter, inserted in the posterior axillary line at the level of the eighth or ninth interspace, was clamped off Then the anterior catheter was clamped and the patient transferred to his room where flasks were connected to the catheters between the patient and the water seal bottles The clamps were then removed and serosanguineous intrapleural fluid draining through the catheters was trapped in the flasks On subsequent days, the administration of erythromycin was continued by the oral or intravenous route

Blood samples were taken from the patients of the pneumonectomy group at 30 minutes, 1, 2, 3, 4, 6, 12, 15, 24, 36, and 48 hours after the 400 mg dose From the patients given the 250 mg dose, blood specimens were taken at 1, 3, 4, 8, 12, 24, 36, and 48 hours Serosanguineous intrapleural fluid samples were drawn at 24, 36, and 48 hours after injection of both doses of erythromycin Twelve hour urine specimens, obtained by catheter left in situ, were collected for the 48 hour period of observation From those given multiple doses of the drug, similar blood samples were taken each day, intrapleural fluid was taken at the end of each 24 hour period just prior to the injection of the next dose Daily total urine specimens were also collected

In the partial resection cases, blood samples were drawn hourly from the patients for the first 6 hours and at the ninth and twenty fourth hours after injection Total intrapleural fluid was collected hourly for the first 6 hours, followed by collection of the fluid in each 6 hour interval for the 24 hour period Urine specimens for 3 hour intervals were collected via a urethral catheter during the first 12 hour period followed by a total 12 hour specimen

Drug concentration was determined on all specimens collected The volume of intrapleural serosanguineous fluid trapped in the flasks from partial resection patients and all urine samples were measured and the total amounts of erythromycin present in the samples were calculated The method used to determine drug concentration was that of Loo and associates,[10] employing the paper disc agar diffusion technique Intrapleural fluids were examined microscopically and cultured for the presence of any microorganisms The patients were observed closely for two weeks in the immediate postoperative period. Particular attention was paid to temperature, and pulse and respiration rates, as well as to any signs of toxic or septic condition of the patients during this period.

RESULTS

A. Intrapleural Fluid and Serum Levels and Urinary Drug Excretion

1. Pneumonectomy Cases.—The graph in Fig. 1 shows the average values of intrapleural fluid and serum levels and urinary drug excretion in patients given a single dose of 250 or 400 mg. At 24 hours, the respective intrapleural fluid levels were 12.2 and 26.5 mcg./ml. declining to 10.1 and 19.8 mcg./ml. at 36 hours, while at 48 hours the respective levels were 4.5 and 6.8 mcg./ml.

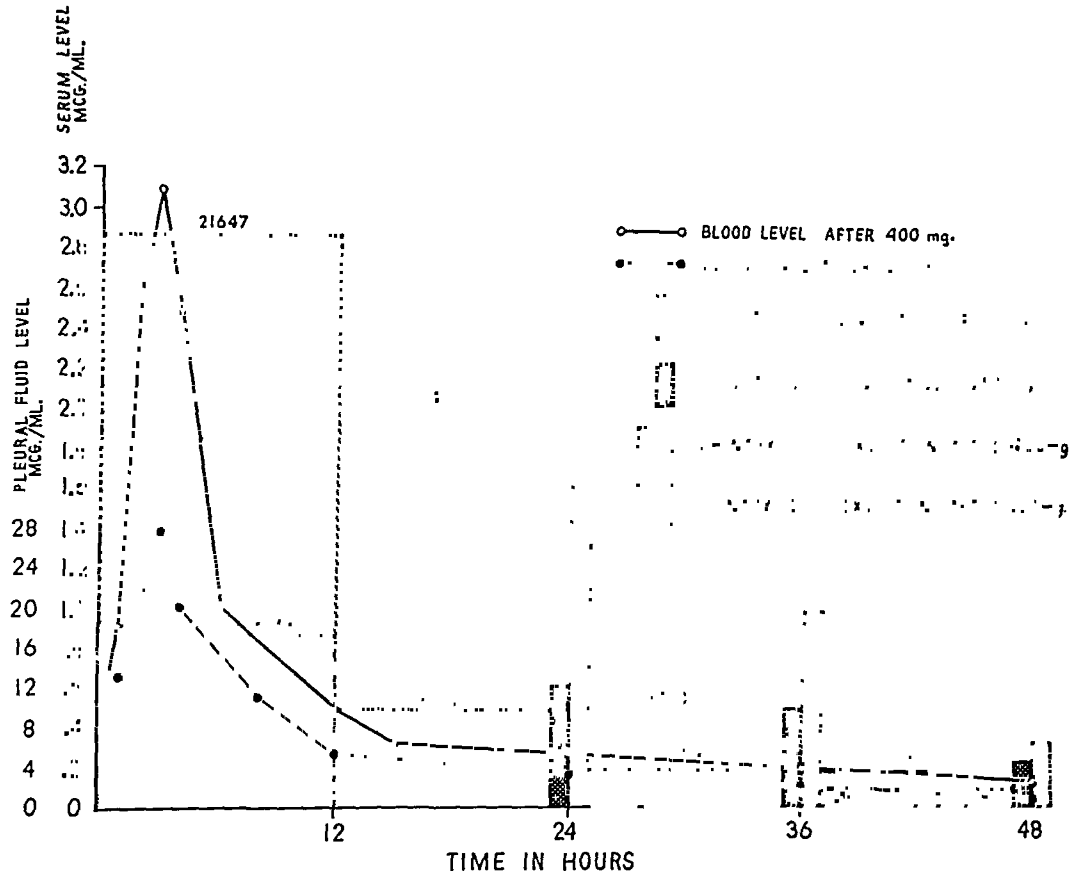

Fig. 1.—Effects on serum of single intrapleural doses of 250 and 400 mg. of erythromycin, intrapleural fluid concentrations, and urinary drug excretion in pneumonectomy patients. Average results from the use of 250 mg. on 8 patients, and 400 mg. on 4 patients.

Figs. 1 and 2 taken from M. López-Belio and Y. Takimura, Intrapleural, Intravenous and Oral Administration of Erythromycin. Comparative Studies of Serum and Pleural Fluid Levels and Urinary Drug Excretion, Antibiotics Annual 1954-1955, Medical Encyclopedia, Inc., New York. Permission granted by Henry Welch, Ph.D., editor.

These concentrations of erythromycin are inhibitory to all susceptible microorganisms. Serum levels followed the same curve as the intrapleural fluid levels, reaching a peak concentration at 3 hours of 1.4 mcg./ml. with a 250 mg. dose and 3.1 mcg./ml. with the 400 mg. dose. Thereafter, there was a gradual decline in the levels until at 24 hours the concentrations were 0.16 and 0.27 mcg./ml., respectively; 48-hour levels were 0.04 and 0.12 mcg./ml.

Total drug excretion in urine in general followed the curve of the serum levels. The total 48-hour drug output in urine was 4.8 per cent of the 250 mg., and 10.5 per cent of the 400 mg. dose administered. During the first 12-hour period with the 250 mg. dose, drug excretion amounted to 52.7 per cent of the total in 48 hours; in each of the subsequent 12-hour periods 30.3 per cent, 11.4 per cent and 5.6 per cent, respectively, of the 48-hour drug excretion were found. Similarly, with the 400 mg. dose, the corresponding figures were 51.6 per cent, 36.1 per cent, 9.0 per cent, and 3.2 per cent.

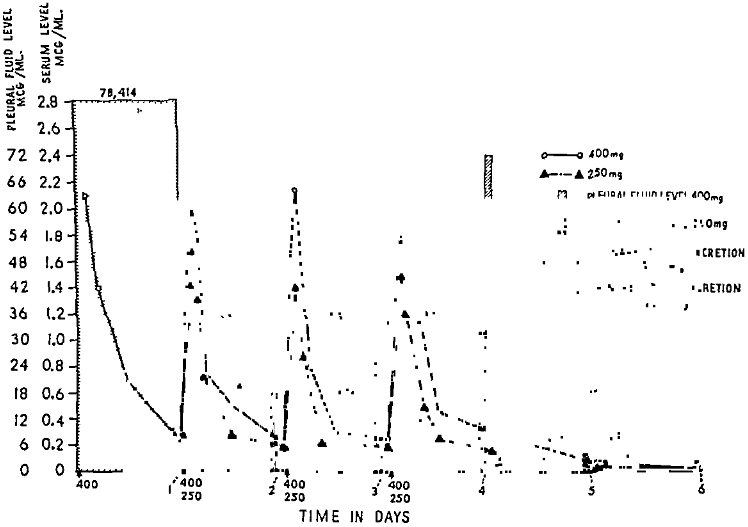

Fig 2.—Effects on serum of multiple intrapleural doses of erythromycin, intrapleural fluid concentrations, and drug excretion in the urine of pneumonectomy patients. Average results from 3 patients who were given initial 400 mg. doses followed by daily instillations of 250 mg., and from another group of 3 patients, given 400 mg. daily for 3 days, after the initial dose of 400 mg.

The effect of multiple doses of erythromycin on serum levels was similar to those seen with the single dose. However, determinations of the drug concentration in intrapleural fluid withdrawn just prior to the daily injection revealed a rising level, increasing from 15.5 mcg./ml., 24 hours after the first injection of 400 mg., to 31.6 and 72 mcg./ml., 24 hours after the last injection of 250 and 400 mg., respectively. Thereafter there was a rapid decline in the levels which, however, were of effective concentration 48 hours after the last injection of 250 mg. and 72 hours after the last 400 mg. dose. Daily urinary drug excretion after the first day remained approximately at a constant level during administration. Average daily drug excretion during administration amounted to 6.1 per cent of 250 mg., and 8.5 per cent of the [illegible] dose. These results are seen in the graph of Fig. 2.

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RES

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B. Clinical Observations

In the group of 18 pneumonectomy patients, during administration of erythromycin, intrapleural serosanguineous fluid was withdrawn daily after surgery. The fluid showed no change in color or consistency and no evidence of bacterial growth was noted with either the 250 or 400 mg. dose given. The postoperative course of these patients was uneventful; temperature returned to normal in 24 to 36 hours, and blood pressure, pulse and respiration rates were all within normal limits. Soft tissue infection failed to develop and postoperative infection of the pleura or lung parenchyma was absent in all patients. One of these patients, however, died on the eighth postoperative day. Death resulted from pulmonary edema due to left heart failure which was confirmed by post-mortem findings. The patient had received the last dose of 250 mg. 48 hours prior to death; immediately after death, cardiac puncture and pleural aspiration were performed. The specimens appeared to be grossly normal. Bacteriologic examination was negative and erythromycin concentrations were 0.04 mcg./ml. in heart blood, and 3.0 mcg./ml. in pleural fluid.

The 12 patients who comprised the partial resection group and were given 250 mg. in single dose and continued on oral or intravenous administration after the first day, also had an uneventful postoperative course similar to the pneumonectomy patients. In all of these patients with intrapleural catheters, infection at the site of insertion of the catheters did not develop. After removal of the tubes the orifices healed by first intention. Postoperative complications, due to infection by pyogenic microorganisms, were absent. One exception was noted in a patient who had had a double segmentectomy (the apicoposterior segment of the upper lobe and the superior segment of the lower lobe) of the left lung. This patient was given erythromycin intrapleurally at the time the chest was closed and later maintained on an oral dosage, when, on the fifth day a bronchopleural fistula with concomitant pyogenic empyema was discovered. General toxic signs were evident and the patient was then placed on 5 days of intensive erythromycin therapy given by continuous intravenous drip. A rapid and remarkable response was noted. Cultures of specimens obtained from the catheter, previously positive for *Micrococcus pyogenes* var. *aureus*, became negative. Subsequently, with continued improvement on oral medication, a thoracoplasty was performed and the patient recovered completely.

DISCUSSION

The effect of intrapleural administration of erythromycin on serum levels appears to be dependent on the type of resection undergone by the patient. The difference is due largely to the presence of the intrapleural catheter as found in partial resection cases or its absence, as in pneumonectomy. In the latter group, there is a build-up of serum levels which reached peak concentration at 3 hours but in the former group the serum levels showed immediate decline from the initial peak value at 1 hour. With a comparable dose, the 3-hour level was approximately one half in the partial resection group compared to that of the pneumonectomy group; coincidentally the former group

2. *Partial Resection Cases.*—The average loss of erythromycin through the intrapleural catheters as well as by excretion in urine, and concentration in blood serum during the 24-hour period in this group of patients after intrapleural administration of 250 mg., is shown graphically in Fig. 3. The total amount of the antibiotic lost in 24 hours through the catheters was 130.11 mg. which is 52.2 per cent of the dose given. In the first hour, 43.5 per cent of the dose was found in the drainage fluid; from the second to the sixth hour, 8.5 per cent was eliminated and only 0.12 per cent was found in the last 18 of the 24-hour period. Total urinary excretion of erythromycin for 24 hours was 5.3 per cent of the dose, or 13.15 mg. In the first 3 hours, 3.5 per cent was excreted, while in 6 hours 4.1 per cent was eliminated; thus 1.2 per cent was found in urine in the last 18 hours. The total loss of erythromycin, therefore, was 57.5 per cent in 24 hours, 55 per cent of the dose being accounted for during the first 3 hours. Concentration of the drug in serum was high after 1 hour, the level being 1.88 mcg./ml. but declined rapidly in keeping with the large amounts lost through the catheters and in urine; however, inhibitory concentration of erythromycin against staphylococci was found in blood at 12 hours.

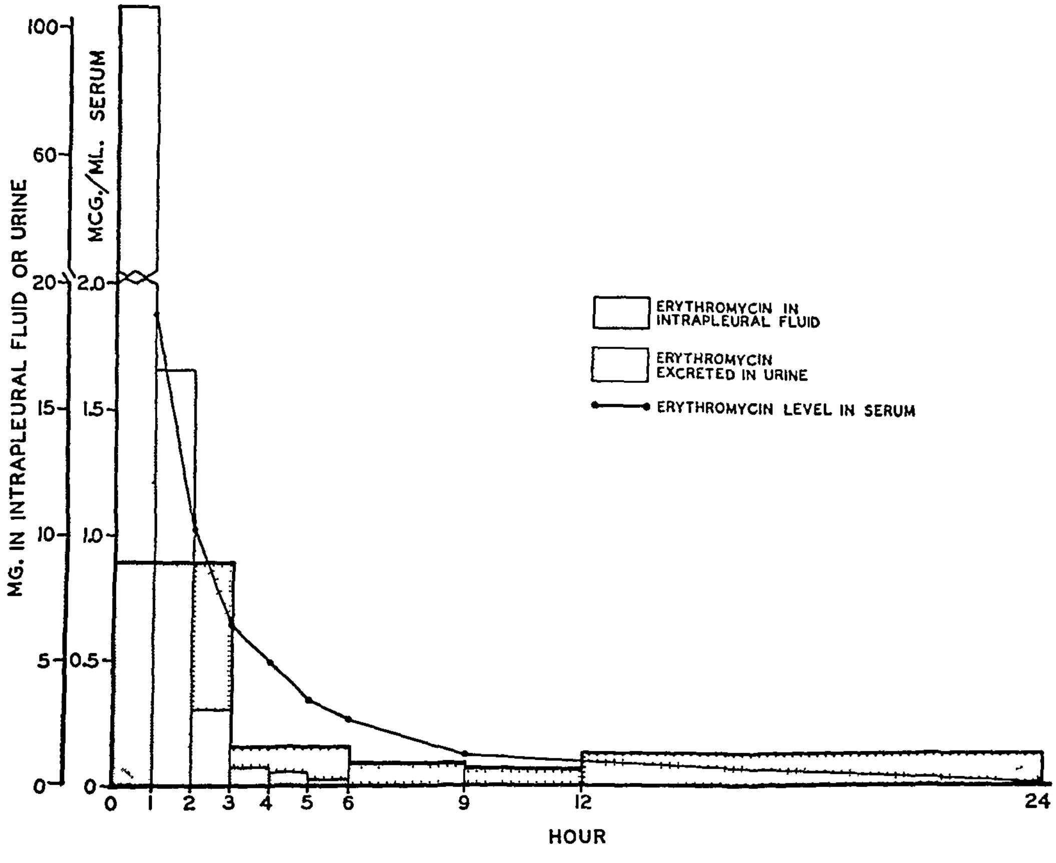

Fig. 3.—Erythromycin serum concentrations, loss through intrapleural catheter, and excretion in urine, after the intrapleural instillation of 250 mg. of erythromycin through the intrapleural catheter as the chest was closed after partial lung resection. Average results from 5 such patients.

B. Clinical Observations

In the group of 18 pneumonectomy patients, during administration of erythromycin, intrapleural serosanguineous fluid was withdrawn daily after surgery. The fluid showed no change in color or consistency and no evidence of bacterial growth was noted with either the 250 or 400 mg. dose given. The postoperative course of these patients was uneventful; temperature returned to normal in 24 to 36 hours, and blood pressure, pulse and respiration rates were all within normal limits. Soft tissue infection failed to develop and postoperative infection of the pleura or lung parenchyma was absent in all patients. One of these patients, however, died on the eighth postoperative day. Death resulted from pulmonary edema due to left heart failure which was confirmed by post-mortem findings. The patient had received the last dose of 250 mg. 48 hours prior to death; immediately after death, cardiac puncture and pleural aspiration were performed. The specimens appeared to be grossly normal. Bacteriologic examination was negative and erythromycin concentrations were 0.04 mcg./ml. in heart blood, and 3.0 mcg./ml. in pleural fluid.

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The effect of intrapleural administration of erythromycin on serum levels appears to be dependent on the type of resection undergone by the patient. The difference is due largely to the presence of the intrapleural catheter as found in partial resection cases or its absence, as in pneumonectomy. In the latter group, there is a build-up of serum levels which reached peak concentration at 3 hours but in the former group the serum levels showed immediate decline from the initial peak value at 1 hour. With a comparable dose, the 3-hour level was approximately one half in the partial resection group compared to that of the pneumonectomy group; coincidentally the former group showed, in the first 3 hours, a loss through the catheters of 51.5 per cent of the drug given. Another difference between the two, which may influence serum levels, is that in the pneumonectomy patient there is a limited pleural area for absorption, whereas in the other patients the pleural surface is more extensive, permitting a more rapid absorption of the drug from the pleural space. Thus, comparison of the 1-hour levels shows that partial resection patients had considerably higher levels than the corresponding ones who had had a pneumonectomy. After these differences, the serum concentration curves show a similar pattern. However, the continued loss of erythromycin through the catheters in the partial resection patients resulted in a shorter period of effective levels; the 12-hour level in these patients corresponding to the 36-hour level in pneumonectomy patients. In pneumonectomy cases, the administration of a larger dose affected serum levels in the expected manner. The 400 mg. dose compared to that of 250 mg. resulted in elevated serum levels and a more prolonged effective concentration. The pleural fluid levels showed similar effects, with the larger dose resulting in higher levels. Hence, more than adequate coverage against susceptible pyogenic bacteria by erythromycin was present in pneumonectomy patients and, to a lesser extent, for a shorter period of time, in the partial resection patients.

Prior to the availability of penicillin, empyema was the most frequent complication following pulmonary resections. However, results with the use of antibiotics as prophylactic agents, particularly penicillin, do not indicate uniform effectiveness of this antibiotic for this purpose in lung resections. Of the 21 resections for suppurative disease of the lung reported by White and his colleagues,[11] 12 patients given penicillin did not develop empyema while all 9 patients in the control group had this complication. On the other hand, of Blades' series[12] of 59 similar cases, 11 of the 29 patients given penicillin developed empyema as well as 12 of the 30 patients without this antibiotic. Neither of these reports shows data indicating the development of empyema as a consequence of bronchopleural fistula. At this institution,[13] of the 25 tuberculous patients undergoing pulmonary resection without antibiotic coverage, 10 had nontuberculous empyema; 4 of the primary type, and 6 secondary to fistula. In contrast to this unprotected series, penicillin given irregularly by the intramuscular or intrapleural route in 21 patients was followed by 2 cases of primary pyogenic empyema and 3 cases secondary to fistula. Subsequent to the 21 cases, a review of 274 consecutive pulmonary resections with penicillin and streptomycin revealed 16 cases of nontuberculous empyema occurring before the tenth postoperative day, 11 resulting from the development of bronchopleural fistula. Therefore, even with antibiotic protection, the presence of a bronchopleural fistula favors the development of an empyema. This was seen in the present study in the one patient whose empyema was secondary to the development of fistula and in whom the prophylactic effect of erythromycin was not evident. Even in this case, erythromycin appeared to be of value in controlling the infection, but it should be noted that its effectiveness was due to the higher drug concentration attained by intravenous infusion and not by oral administration, although the latter route was sufficient to prevent infection in patients without a bronchopleural fistula. Thus, the intrapleural dose in the partial resection cases should be augmented, generally in 12 hours, by oral or intravenous administration; the intravenous route is indicated especially when the likelihood of infection is present. It is felt that this is a particularly important point to consider since tissue concentration of the drug may be related directly to the serum concentration and that the latter, although relatively unimportant in itself, is a measure of the drug concentration at the focus of infection.[14, 15] Indeed, it is known that with penicillin the diffusion from the blood stream into the pleural space is inadequate.[16, 17] However, we have found erythromycin to have considerably greater diffusibility.

In most of the above reports, there is little or no information on the resistance or sensitivity of the microorganisms to penicillin, although this information is vital in the evaluation of the effectiveness of this drug. Further information required for the adequate evaluation of any prophylactic agent in pulmonary resection should concern the type of resection undergone by the patient. As mentioned previously, there is a difference in drug concentration in serum and in intrapleural fluid, depending upon the type of resection performed, but aside from this consideration is the fact that pneumonectomy patients with a complicating fistula invariably develop empyema whereas in partial resection patients development of a fistula does not necessarily result in empyema.

SUMMARY AND CONCLUSION

Erythromycin was found to be an effective prophylactic agent against pyogenic empyema in pulmonary resection cases except in cases in which empyema was secondary to the development of a bronchopleural fistula. The effectiveness was dependent on the type of resection; specifically, the presence or absence of intrapleural catheters was the major factor. In the pneumonectomy group, effective concentration of the drug was found 48 hours after a 250 mg. intrapleural dose, and 72 hours after a dose of 400 mg., intrapleurally. The partial resection cases, however, had a more limited period of effective antibiotic coverage because approximately 50 per cent of the drug was lost through the intrapleural catheters, during the first 3 hours. Thus, in the latter type of case, the intrapleural dose should be augmented by oral or intravenous administration, depending on the condition of the patient. In patients without bronchopleural fistula, erythromycin was felt to be effective in preventing the development of empyema; but even in those cases of fistula and concomitant empyema, the drug is felt to be of value in bringing about a marked improvement in the general condition of the patients so that a further surgical procedure becomes feasible at an earlier time. The important factors necessary for the proper evaluation of antibiotics as prophylactic agents in pulmonary resection are considered to be the presence or absence of bronchopleural fistula, adequate local concentration of the drug, and sensitivity or resistance of the particular microorganisms to the antibiotic under study. The role and importance of bronchopleural fistula in the development of empyema are discussed.

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Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty seventh Annual Meeting of The American Association for Thoracic Surgery will be held May 4, 6, and 7, 1957, in Chicago, Illinois Headquarters will be at the Palmer House

Requests for Hotel Reservations

These should be mailed directly to Mr Edward Langford, Reservations Manager, Palmer House, Chicago Please mention this Association, the type of accommodation desired, the date, and approximate hour of arrival and departure If accommodations are desired elsewhere in Chicago, please communicate directly with the hotel of your choice

Thoracic Surgery Forum

The Thoracic Surgery Forum will be continued as a special session at the 1957 meeting The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies, and modified or new surgical techniques The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferal to the Regular Program

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper

All Thoracic Surgery Forum papers will be published together in one issue of the JOURNAL Maximum length 3000 words without illustrations If illustrated, an appropriate number of words must be subtracted for each cut used

Abstracts of Papers

Abstracts of all papers for presentation at the 1957 meeting must be received on or before Dec 15, 1956, otherwise they will not be considered by the Program Committee

Abstracts should be labeled "For Thoracic Surgery Forum," or "For Regular Program" The abstracts should contain from 200 to 250 wor
accurately reflect the contents of the completed

Five, repeat, five copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 600 South Kingshighway, St. Louis 10, Missouri.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. Karl P. Klassen, The Ohio State University, Columbus 10, Ohio, before Dec. 15, 1956.

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions. If the films are well labeled, it will not be necessary for the author to be present for comment.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec. 15, 1956, otherwise the application will be deferred for consideration until the 1958 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. O. T. Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn.

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year. The new letters of recommendation should also be sent to Dr. Clagett, the Chairman of the Membership Committee.

The Journal of Thoracic Surgery

Vol. 32 September, 1956 No. 3

Original Communications

CONGENITAL DIAPHRAGMATIC HERNIA AND HYPOPLASTIC LUNG

A Clinical Evaluation

Benson B. Roe, M.D., and H. Brodie Stephens, M.D.
San Francisco, Calif.

Congenital *diaphragmatic hernia is reported to be a surgically correctible* condition with satisfactory results and a low mortality rate.[1] Published series[2-7] of successful surgical closures of this defect would seem to indicate that operative intervention promptly after birth is mandatory for survival. However, this developmental failure of closure of the pleuroperitoneal sinus, or foramen of Bochdalek, is a relatively rare condition which frequently is not diagnosed until an infant reaches the autopsy table. The serious respiratory embarrassment, thought to be the result of abdominal viscera in the chest, often causes death in the first few minutes of life. In those patients coming to surgery, and particularly in the newborn infant, this disturbed physiology is a significant hazard.

It has been our observation that the compressed and hypoplastic lung in the previously occupied pleural space could not be expanded after removing the abdominal organs. Mention of this problem is notably lacking in the surgical reviews, although association of the two conditions was reported as early as 1893 by Schmit.[8] Dorsey,[9] Tolins,[10] and Ladd and Gross[4] did mention atelectatic lung and respiratory difficulties after operation, but failed to recognize hypoplasia.

The reported clinical experience with congenital diaphragmatic hernia reveals a wide variation in operative results from Truesdale's[3] survival rate of 92 per cent to the 43 per cent survival of the 7 cases reported by Baumgartner and Scott.[11] Contrary to common belief, the over-all survival in this

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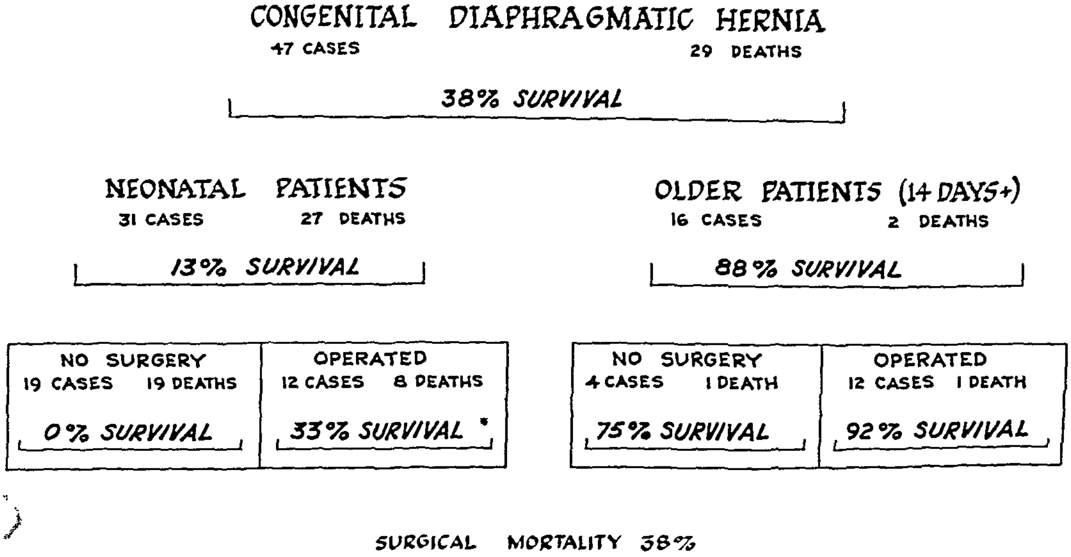
anomaly is far from satisfactory,[12, 13] and the observations of pathologists are distinctly less encouraging. Edith Potter,[14] in discussing congenital diaphragmatic hernia in her text on infant pathology, states, "In our experience associated pulmonary hypoplasia has been so great that the lungs were incapable of supporting extra-uterine existence." More recently, Campanale and Rowland[15] have reported on this neglected aspect of the problem. To our knowledge, however, there have been no observations on the incidence of hypoplastic lung in congenital hernias of the diaphragm, either in the surgically correctible group[1-7] or in those studied at post mortem.[16] This discrepancy between the optimism of the surgical reports and the less favorable observations of the pathologist suggested the value of further investigation to determine the factors influencing survival.

TABLE I



CONGENITAL DIAPHRAGMATIC HERNIA
47 CASES 29 DEATHS
38% SURVIVAL

NEONATAL PATIENTS
31 CASES 27 DEATHS
13% SURVIVAL

NO SURGERY	OPERATED
19 CASES 19 DEATHS	12 CASES 8 DEATHS
0% SURVIVAL	33% SURVIVAL *

OLDER PATIENTS (14 DAYS+)
16 CASES 2 DEATHS
88% SURVIVAL

NO SURGERY	OPERATED
4 CASES 1 DEATH	12 CASES 1 DEATH
75% SURVIVAL	92% SURVIVAL

SURGICAL MORTALITY 38%

* OPERATED AT 7 DAYS, 5 DAYS, 2 DAYS & 1 DAY

Hospital records and autopsy protocols were reviewed for all cases of congenital diaphragmatic hernia in eleven San Francisco hospitals for as long as records were catalogued, up to twenty years. Hernias through the foramen of Morgagni, esophageal hiatal hernias, eventration of the diaphragm, and all adult hernias were excluded from the series. A total of 47 cases were analyzed for pregnancy factors, obstetrical course, birth weight, presenting signs, time of operation, operative findings, length of survival, and autopsy observations. These data yielded no pertinent information of value in determining the cause or prognosis of the disease. No pregnancies were complicated by disease; obstetrical delivery was unremarkable; birth weights were normal except for 3 infants weighing under five pounds. Associated congenital anomalies were rare. Two patients in the series were consecutive siblings of the same parents, fourteen months apart.

The over-all mortality rate was 62 per cent which was comprised largely of the newborn infants that never reached surgery. Conversely, almost all of the surviving patients had passed the early neonatal period (2 weeks to 2½ years) before coming to surgery. Since these two groups apparently are not comparable, they are analyzed separately to emphasize the prognostic differences and in order to consider the management problems in the newborn group (Table I). The 87 per cent combined mortality in the early group is in striking contrast to the 12 per cent fatalities in the older group. Of greater importance is the difference in operative results between the two groups, each with 12 patients operated upon, among the newborn patients there were eight deaths, whereas among the older patients there was only one. Furthermore, 2 of the 4 survivors in the early group were 5 and 7 days old, respectively, at the time of operation. In the older group, 7 patients were between 18 days and 8 weeks old, the others ranged from 6 months to 2½ years. The only fatality was in a 6 month old child who presented with bronchopneumonia.

Unfortunately, both operative reports and autopsy protocols were often lacking in detailed description of size and expandability of the lung. Table II summarizes these surgical observations concerning lung appearance, in only 5 of 24 patients was satisfactory lung expansion described, whereas in 10 cases, the surgeon noted that the lung remained small and collapsed. Autopsy observations (Table III) indicate that in size the lung on the hernial

TABLE II. SURGICAL OBSERVATIONS ON LUNG EXPANSION IN CONGENITAL DIAPHRAGMATIC HERNIA

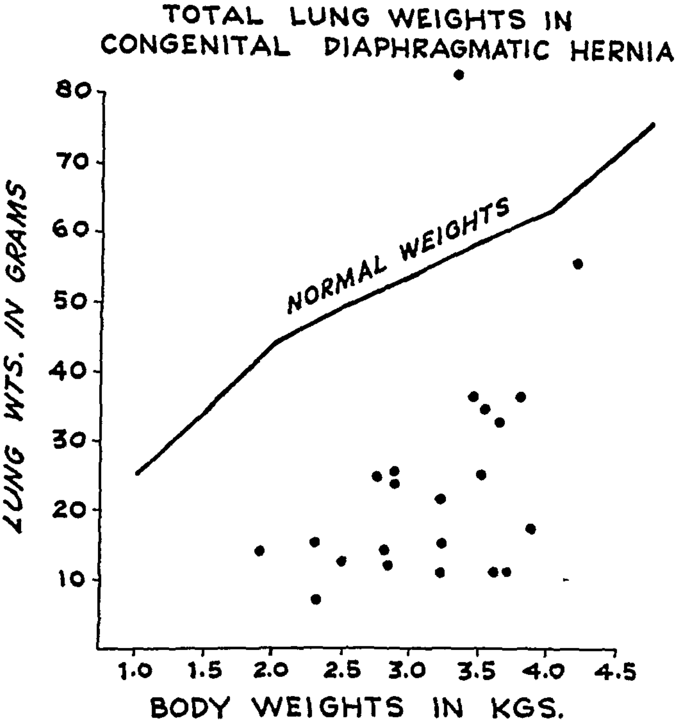
Satisfactory lung expansion	5
Partial lung expansion	1
Little or no expansion from small nubbin	10
No comment in operative note	8

TABLE III. CONGENITAL DIAPHRAGMATIC HERNIA AUTOPSIED LUNG WEIGHT RATIOS

LEFT	RIGHT	RATIO
1.5	11.6	0.13
4.5	27	0.17
6	30	0.20
2	9	0.22
10	46	0.22
2.5	10	0.25
7	25	0.28
9	26	0.35
6.5	17	0.41
4.0	9.5	0.42
8	*3.5*	0.44
11.3	25	0.45
33	55	0.60
10	15	0.66
15	*10*	0.66
10	11	0.91
"One third"		(0.33)
"One third"		(0.33)
"Much smaller"		
"Small, poorly developed"	"Normal"	
"Definitely smaller"		
		Average Ratio 0.39

Note. Side of hernia in italics

side is often only a small fraction of the contralateral lung (average ratio: 0.39). Perhaps of greater significance is the total lung weight (Table IV) which is almost invariably far below the predicted norm according to the figures published by Potter and Adair[17] (Fig. 1). Since the pleuroperitoneal



ADAPTED FROM POTTER & ADAIR: NORMAL LUNG WEIGHTS FOR BODY SIZE, 1144 AUTOPSIES

Fig. 1.

TABLE IV. CONGENITAL DIAPHRAGMATIC HERNIA AUTOPSY LUNG WEIGHTS

COMBINED LUNG WT. (GRAMS)	*ESTIMATED NORMAL WT. (GRAMS)	PER CENT OF NORMAL
7	48	15
11	62	18
12	61	19
12	57	21
12	53	23
13	53	24
14	42	32
14	52	27
15	48	31
21	57	37
22	53	41
24	53	45
25	52	48
25	59	43
32	61	52
35	60	59
36	63	57
37	59	62
56	67	84
88	58	138
	Average per cent of normal lung weight	44

*From Potter and Adair[17]: average infant autopsy lung weight according to body weight.

sinus normally closes in the fourth fetal month, it is not surprising that continued occupation of the pleural space interferes with lung growth on one side, but it is of interest that the combined lung weight should be less than

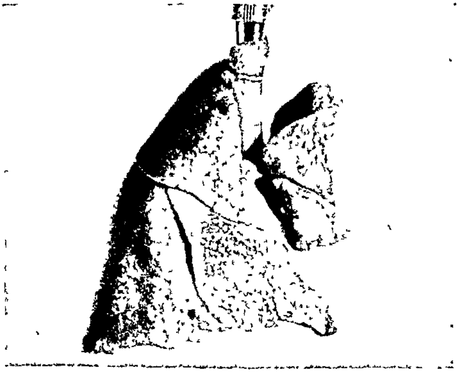


Fig. 2.—Inflated lungs of patient with congenital diaphragmatic hernia which caused death a few minutes after birth. Note left lung is very small, even under pressure. Combined lung weight 12 Gm. (body weight, 3,200 Gm.); normal for this infant about 57 Gm.

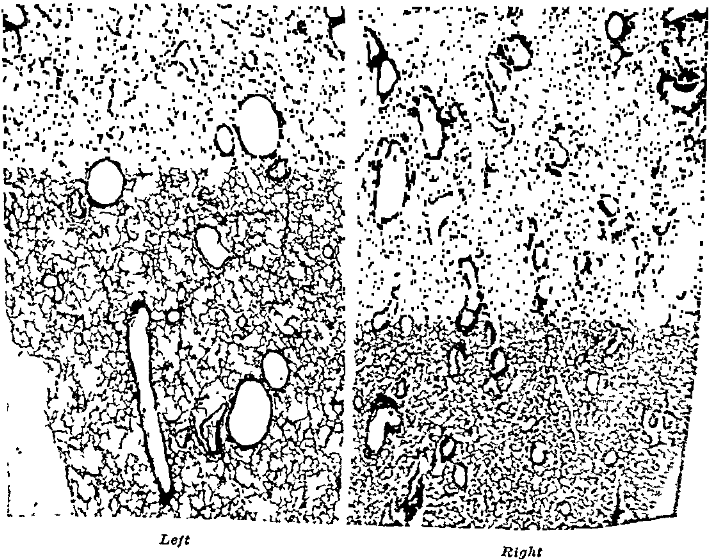
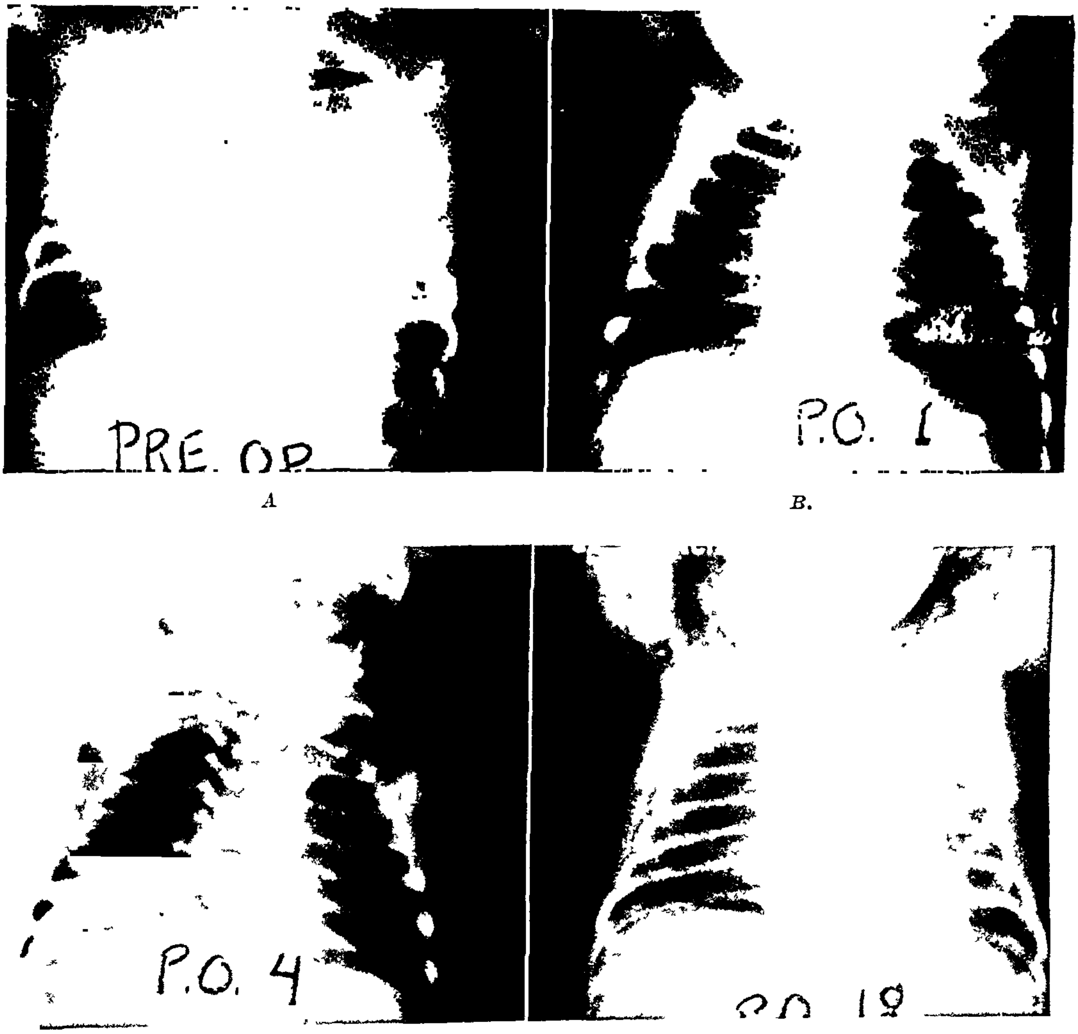


Fig. 3.—Photomicrographs of inflated autopsied lungs shown in Fig. 2. Note comparable size of vessels and bronchi, small alveolar spaces, thickened alveolar [illegible] and absence of atelectasis on left side. (×10; reduced ½.)

50 per cent of normal in the majority of autopsied cases (Fig. 2). Microscopic sections of the undeveloped lung showed variably thickened alveolar septa, thick pleura, and some cystic dilatation in sparse alveolar tissue (Fig. 3), but the bronchi and blood vessels were of normal size.

Postoperative roentgenograms demonstrated a variable pattern. In at least 3 cases, the undeveloped lung on the side of the hernia was not immediately expanded but was observed to fill out over a period of several days or weeks (Fig. 4). Whether these lungs are the emphysematous results of an overexpanded hypoplastic organ, or the true growth of new alveolar tissues, is undetermined. The fact that there was no apparent shift of the flexible mediastinum suggests that the underdeveloped lung must still possess a growth potential. What effect delaying surgery would have on this process is also undetermined.



A *B.*

C. *D*

Fig 4.—Serial chest roentgenograms on successfully repaired congenital diaphragmatic hernia in a newborn patient Note gradual lung expansion on the left. *A*, Preoperative; *B*, first day postoperative, *C*, fourth day postoperative, and *D*, eighteenth day postoperative, fully expanded.

Statistical analysis of the cause of death was impossible from the material available In some instances, other anomalies or surgical complications could share the blame, but in general the autopsy observations were less revealing than the clinical course marked by respiratory distress Tension pneumothorax was a post mortem finding in 4 operated patients and suggests that vigorous attempts to evacuate the pleural space may lead to rupture of the hypoplastic lung Smith,[18] however, showed that it took pressures between 20 and 30 cm of water to expand the normal lung at birth

DISCUSSION

It is possible that clinical inexperience, technical difficulties, and other hazards of operating on the newborn infant are responsible for the high mortality rate However, it is significant that the surgical results are distinctly better under the same circumstances after two weeks of life and better respiratory compensation Other surgical procedures are tolerated by the newborn child without significantly greater mortality than after a few weeks of life Undoubtedly the process of natural selection in the early neonatal period removes those patients with inadequate respiratory capacity But it is likely that this period is also of positive value in improving the gradually acquired ventilatory capacity of an infant and rendering him a better surgical candidate after a few days despite the hernial contents in the chest Engel[19] has pointed out that even the normal newborn infant has a very poor pulmonary reserve and a very high physiologic dead space, alveolar air filling is not complete for several days,[20] during which time ventilation improves significantly

Proponents of early surgical intervention would argue that no harm is done in an unsuccessful attempt to correct those whose unpredictable fate has already been sealed It would be their hope to salvage the borderline patient who might have an expansible lung and survive if the mechanical pressure is removed, but who otherwise would not survive It is our [illegible] however, that more patients with marginal respiratory capacity at b[illegible] will survive if surgical intervention is delayed ten days than if ope[illegible] is carried out immediately Obviously those with inadequate capacity will die whether or not they are operated upon

The surgical literature contains little support for this thesis Donovan[21] notes the greater hazard in younger patients but urges early operation anyhow, Harrington[6] alone recommends delaying operation Reports of large diaphragmatic hernias in adults[22, 23] further demonstrate that the disease does not always require immediate correction

Obviously the dispute cannot be settled without further knowledge, but our study suggests that pulmonary hypoplasia is such a common and serious associated problem that the benefits of early expansion may be overestimated When surgery is performed it is essential that every adjunct be used to support the marginal respiration postoperatively A high oxygen atmosphere alone may not suffice, intermittent gentle positive pressure to aid in alveolar aeration should improve respiratory capacity Tracheostomy to reduce dead space may be helpful despite its management difficulties in the infant Drainage of the pleural space is strongly recommended for protection against tension pneumothorax and to promote gentle and gradual expansion of the hypoplastic lung. Vigorous efforts to expand the lung at operation may cause serious damage and should not be attempted.

SUMMARY

1. Forty-seven cases of congenital diaphragmatic hernia were analyzed for factors determining prognosis.
2. Mortality in the newborn group was 87 per cent as compared to 12 per cent in the older patients (over 14 days of age), suggesting that natural selection plays an important role in the results.
3. Surgical mortality was 67 per cent in the newborn infant and 8 per cent in the older group.
4. Hypoplastic lung was an associated finding in nearly all cases autopsied. Average combined lung weight was 44 per cent of normal.
5. Undeveloped lung on the hernial side was recorded in 10 surgical cases and in 17 autopsied cases with weight ratios from 0.13 to 0.91.
6. On the basis of these data, a thesis is presented for postponing early operation in favor of gradual improvement in marginal ventilatory function.
7. Recommendations are made for improving the management of the patient with inadequate lung tissue.

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DISCUSSION

DR GABRIEL SELEY, New York, N. Y—*I enjoyed this paper and I would like to* report an unusual pulmonary complication and presenting symptoms of a Bochdalek pleural peritoneal hernia The patient was a 35 year old housewife whose chief and only complaint was recurring hemoptysis Roentgenographic studies showed an ill defined density in the left lower chest Breath sounds were absent over this area and bronchoscopy showed no disease in the bronchial tree Because of some translucency present in this area, a hernia was suspected and barium enema showed a large amount of large and small bowel in the left pleural cavity This patient was operated upon, and upon entering the pleural cavity almost the entire large and small bowel including the cecum and appendix were found There was no pleural sac The hernia ring was of fairly good size In order to reduce the contents, the patient was placed in a practically standing position on the operating table The contents were reduced and the ring was closed, and an attempt was made to expand the lung It was noted at this time that the left lower lobe was definitely hypoplastic and *that the entire diaphragmatic surface showed a severe constricting* ring which coincided with the size of the hernia ring This portion of the lung could not be re expanded and was severely congested The chest was closed in the usual manner with drainage, the patient did well postoperatively and has remained well for five years There has been no evidence of recurrent hemoptysis

It is my impression that this patient represents an adult who had a hypoplastic lung with a pleuroperitoneal hernia who obviously survived this complication, and then apparently had an incarceration of the lung in the hernial ring which produced hemoptysis I would like to ask the essayist whether he has encountered any such case, or if any other members of the Association have seen this complication

DR WILLIS J POTTS, Chicago, Ill—*This is a very fine paper, beautifully* presented by Dr Roe, and I believe just four words of it—"The lung will grow" We are far less concerned about the hypoplastic lung than we are about getting the diaphragm repaired quickly The ill infants with a diaphragmatic hernia are real emergencies and if not operated upon promptly will die If the child can live ten to twelve days after birth the hernia usually is not severe, that is, the respiratory space is not too extensively encroached upon by the misplaced intestine From our experience with infants with diaphragmatic hernia, I would say that the real emergencies are practically always those who do not have a sac If there is a sac, *the extent of herniation of the bowel into the chest* is limited and an emergency rarely exists

Our mortality rate in the newborn infant group of diaphragmatic hernias is 25 per cent In the older age group, there has been no mortality Two of the deaths were definitely our fault The first, in keeping with what Dr Roe has said, was an infant with a tiny hypoplastic lung as big as the end of my thumb (Incidentally, the left lung is always small and undeveloped in the infant who is born with a diaphragmatic hernia and has all the abdominal organs in the left chest) The anesthetist made pressure on the anesthetic bag and blew out the good lung *on the right side Death occurred It is impossible* to dilate the miniature lung Leave it alone and it will grow and expand in time The second death illustrates an important point in the immediate postoperative *treatment which is now routine* As the last stitch is put in to close the diaphragm we make negative suction on a catheter in the chest to withdraw as much air as possible from the left chest cavity The difficulty is that some air may leak into the chest while the abdomen is being closed and thereby prevent complete expansion of the left lung That is what happened in this case and the child died of anoxia We now make it routine after the abdomen is closed, to aspirate the left chest with a needle and remove as much air as possible with a moderate degree of negative suction. We often can remove as much as 50 c.c. of air from the left chest. The procedure, of course, increases the respiratory space by that much.

We do not drain these chests. There is nothing to drain and, besides, the danger of air getting into the chest through or alongside the tube is considerable. Draw out the air and the lung will expand. I agree with Dr. Roe, "The lung will grow."

DR. JOHN S. CHAMBERS, San Diego, Calif.—In connection with Dr. Roe's paper and Dr. Potts's comments, I would like to show slides of chest x-rays of a 2½-week-old infant with pulmonary agenesis and contralateral diaphragmatic hernia.

(Slide) There was a story of five days of respiratory distress preceding this film. The infant showed a left anterior diaphragmatic hernia through the Morgagni foramen which appeared on both the posteroanterior and lateral films. No aeration at all was seen in the right chest. The heart was pulled toward the right. The question arose as to whether this represented atelectasis, hypoplasia of the lung, or perhaps congenital absence of the lung. Bronchoscopy was performed and only a 0.5 cm. stump of the right main-stem bronchus was found. Following bronchoscopy the diaphragmatic hernia was repaired transabdominally, the pleural cavity not being entered as a hernia sac was present. It was noted at operation that there was marked paradoxical motion with respiration of the abdominal contents through the diaphragmatic hernia. After repair of the hernia, the infant did well.

(Slide) This chest x-ray was taken two years later. The absence of aeration of the right lung is still evident, there being either an atresia or a marked hypoplasia of the lung on the right.

DR. MARK M. RAVITCH, Baltimore, Md.—We should at least make mention of the fact that these children all have, or will have within a few hours of birth, intestinal obstruction, and that they may succumb to intestinal obstruction or gangrene or perforation of the intestine or stomach or, on the right side, strangulation of the liver, regardless of the state of the lung; an additional reason for immediate operation. We take the attitude that operation should be undertaken the moment the diagnosis is made. Unless I misread the slides Dr. Roe presented, he indicated that in those children who were not operated upon immediately after birth, the mortality was almost 100 per cent; and in those who were operated on immediately the mortality was about 33 per cent. We do like the intercostal tube even after the abdominal approach, with constant negative pressure gently bringing out the lung, and make no attempt to forcibly inflate the lung. I did not see in the roentgenograms any catheter in the stomach. The two tubes, one in the stomach to empty it completely, placed the moment the diagnosis is made and constant suction applied, and the one in the thorax, we think are almost as important as anything else which may be done.

DR. OTTO BRANTIGAN, Baltimore, Md.—I too enjoyed this excellent presentation by Dr. Roe. I rise to relate a single experience which may be of help. It is true that there will be hypoplastic lungs, bronchial atresia, or even congenital absence of the lung, so that one cannot expect to fill the pleural space by lung expansion. However, there may be failure of expansion caused by a condition similar to fetal atelectasis where the lung seems reasonably normal if it can once be expanded. I encountered one instance in a newborn infant where the anesthetist was unable to expand the lung on the operated side. We hesitated to apply too much pressure to the intratracheal tube for fear of rupturing the opposite lung. However, in this single instance I was able to grasp the main bronchus between two fingers and occlude it. A No. 20 needle was inserted into the bronchus. A 10 c.c. syringe was used to inject air into the bronchus, which caused beginning expansion of the lung. Once expansion was started the anesthetist was able to control it from that point on It did not completely fill the pleural space It seems that this experience might be repeated It eliminates the fear of too much pressure on the opposite lung and there seems little to be lost and little danger if carried out with caution

DR H BRODIE STEPHENS, San Francisco, Calif—I too have enjoyed this presentation of Dr Roe's I think the people here will get the point of his paper In a case that I encountered, I tried to get the hypoplastic lung to expand and I thought that was the way to manage this difficulty, and the lung would not come up In the postoperative management, we undoubtedly put too much negative pressure on the involved pleural side, and reruptured our repair That is why Dr Roe went into this subject and I think this presentation is in order

Certainly if one encounters a hypoplastic lung at the time of repair and the lung does not come up readily, then the surgeon should seek any method for expansion You heard what Dr Potts had to say, if you leave the lung alone it will come up, and I think that is the essential value of this presentation

DR DE WITT C DAUGHTRY, Miami, Fla—Dr Roe has focused our attention upon a very important condition Foramen of Bochdalek hernia is not a common congenital anomaly but the results are so poor generally that I believe it is worthy of very careful appraisal Our experience has not been good with th[illegible]dition and I believe it is in part due to the fact that most of these cases I ha[illegible] have deteriorated greatly and are in rather poor condition when thoracic surgical consultation was requested

It has been rather interesting to me to rev[illegible] records on these patients and to find that many of them were in fair to good [illegible] at birth and remained so for twenty four to seventy two hours before any [illegible] deterioration of the condition occurred The failure to recognize these [illegible] became serious or death actually occurred, I believe, is due to failure of [illegible]ination and failure to obtain x rays of the chest on these newborn infants [illegible]tory difficulty I know of a number of cases in which a diagnosis was [illegible] until an autopsy was performed

I certainly believe it will be a step backw[illegible]end that any delay in treatment be accepted after the diagnosis is made Th[illegible] on the above statement that many of them remain in good condition for [illegible] or two or three days after birth and then suddenly deteriorate before [illegible] nt can be instituted I would certainly like to make a plea for surgical cor[illegible] earliest possible moment It seems to me that our salvage rate will be [illegible] her by such management Of course, the good ones are those without a marked [illegible] interference with pulmonary function, who may survive for some time or even [illegible] veral years of age But that is no argument against a really aggressive approach to the problem

There does seem to be a hypoplasia or at least a lung that occupies less than normal volume for the first few days or possibly the first few weeks of life I am not aware of any cases in which there has not been proper expansion or development over a period of a few days or possibly a few weeks after surgery

I would like to illustrate what I have been trying to say by showing a slide of the chest x ray and autopsy findings of a patient who seemed to be in good condition at birth, but slowly deteriorated over a period of forty eight hours and died within one hour after thoracic surgical consultation was requested and while the anesthetist was preparing the patient for surgery This slide of the x ray reveals the left thorax to be filled with abdominal content and the heart and mediastinum displaced almost against the right lateral thoracic cage, revealing only a very small rim of aerated lung at the base and at the apex on the right In other words, there could not be more than 25 per cent aeration of the right lung This slide (a colored photograph) taken at the autopsy table, reveals a portion of the stomach and the descending colon in the abdomen, with the a[illegible] lung from the hernial neck into the abdomen The next slide shows [illegible] the abdominal contents to be located in the left thorax, marked [illegible] on the speed with which the local physician can evaluate the trauma and institute emergency and supportive therapy until the specialty teams can be consulted. We can expect an ever increasing number of serious chest injuries because of the steady and inevitable increase in speed and congestion on the highways and airways. Approximately 25 per cent of deaths from traffic accidents are due to chest injuries.[11] It is imperative that all physicians familiarize themselves with emergency management. We have been encouraged by the fact that a number of our patients with severe chest injuries who were rapidly failing with the usual modern means of treatment, quickly stabilized and eventually recovered by the use of continuous mechanical hyperventilation. The first of these cases treated by this method is recorded.[10]

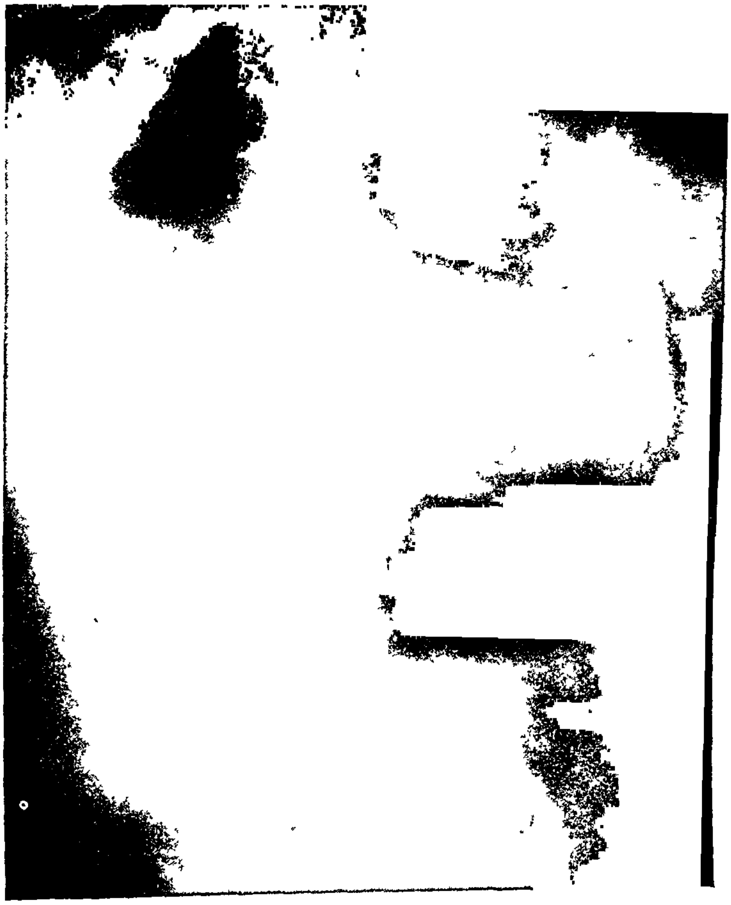


Fig. 1.—X-ray of chest on admission, showing multiple rib fractures, bilateral tension hemopneumothoraces, acute gastric dilatation.

CASE REPORT

In June, 1954, a 51-year-old man was slowly rolled, like pie dough, into an 8-inch space between a diesel locomotive and a steel furnace. He was admitted moribund, in deep shock, with multiple bilateral fractures of all ribs, costochondral separations, bilateral tension hemopneumothoraces, fractures of the sternum, clavicles, pelvis, crushing injuries of the liver and genitourinary tract, paralytic ileus, and acute gastric dilatation (Fig. 1).

The patient was simultaneously treated for shock as bilateral intrapleural catheter ater trap drainage was carried out along with tracheotomy. The anterolateral chest wall as partially stabilized with soft tissue traction by the method of Hudson.[11] Long metal ins were passed under the pectoralis and serratus anterior muscles on each side (Fig. 2). preader bows were attached and traction applied to an overhead frame (Fig. 3). Although he paradoxical motion was partially corrected, respiratory acidosis continued due to inade-uate ventilation because of actual lung destruction and pulmonary edema (Fig. 4). arious demand flow and pressure cycled respirators were tried. These machines did not entilate the patient adequately because they were activated by the patient's own weak espiratory efforts or did not deliver constantly adequate exchange of gases. The piston ype intermittent positive pressure respirator developed by Mörch[12] was then applied. The atient's condition then improved from a semicomatose state of respiratory acidosis to a ore comfortable and alert state of alkalotic apnea. The pH was kept in a range of pproximately 7.45. Lung inflation and deflation were [illegible] maintained rhythmically nd smoothly with loss of all paradoxical motion. This stopped all overriding and grinding otions of the broken rib ends and promoted their healing. Soft tissue traction was dis-ontinued as soon as we realized that complete stabilization of the chest was to be obtained ith mechanical ventilation (Fig. 5). When mild respiratory alkalosis was achieved, all espiratory motions ceased. Mechanical hyperventilation was maintained for thirty days ntil the patient was able to breathe adequately without the assistance of the machine. he CO_2 and pH of the blood were checked twice daily and electrolyte studies carried out s needed. No serious deviations from normal were found in these studies. The patient was ischarged from the hospital fifty one days after the injury and has returned to his work. ince we felt that this treatment by mechanical hyperventilation had allowed the survival f a patient otherwise thought to have a hopeless prognosis, we have now used the same rinciples of management in a number of severe chest and combined head and chest in-uries with equally good results.

General Principles of Treatment.—The principal effect of lung injury and aradoxical motion of the chest wall is to reduce pulmonary ventilation. This, n turn, leads to and aggravates, hypoxia and hypercarbia, pulmonary edema, telectasis, pneumonitis, and depression of the respiratory center. All of these actors compound one another and lead to death. In the past, the major atten-ion of treatment has been focused on the stabilization of the chest wall to elieve paradoxical motion, and indirectly improve ventilation. Adequate entilation alone can break the vicious cycle of events and correct all of the oxious contributing factors listed. These efforts to improve ventilation must e rapidly instituted. As in all emergency therapy, it must be remembered hat "first things come first." In other words, each situation must be cor-ected in the order of its urgency.

The patient should have an *upright* chest x-ray immediately on admission o allow accurate evaluation of the injuries. The treatment of shock, the decom-ression of hemopneumothoraces, and the establishment of a clear airway are sually all of equal urgency because continuation of any one of these alone could ause the rapid demise of the patient. An airway must immediately be estab-shed by means of a bronchoscope or an endotracheal tube to aspirate secre-ons and administer oxygen under positive pressure. A tracheostomy can en be carried out over the tube which can then be withdrawn and replaced in e tracheostomy wound. After these situations are under control, the ne roblem by order of urgency is that of the paradoxical mot wall. When the bony support of the chest wall is broken, the bellows action of the diaphragm and accessory respiratory muscles, which draw air into the lungs, is markedly reduced. As the diaphragm descends in an attempt to reduce the intrathoracic pressure, the atmospheric pressure compresses the flail chest wall. This reduces, in varying degrees, the amount of air inspired into the lungs; or in effect, enormously increases the amount of dead air space within the lungs. In expiration, as the intrathoracic pressure exceeds the atmospheric pressure, the flail chest bulges outward so that very little air is expired. Thus, a large proportion of the air remains within the confines of the thorax and pendulates back and forth from the alveoli to the tracheobronchial tree with inspiration and expiration. Any diminution of this dead air space will benefit the patient's ventilation.

Carter and Giuseffi[13] have pointed out the advantages accrued from tracheostomy. The dead air space, represented by the volume of the nasal. pharyngeal, and laryngeal air passages which can be short-circuited by tracheostomy, amounts to approximately 100 to 150 c.c. The authors point out that the elimination of this dead space results in more effective ventilation, a diminished resistance to inspired and expired air, and thus reduction of the paradoxical motion of the unstable chest wall. Poor ventilation immediately leads to inadequate absorption of oxygen and elimination of carbon dioxide. The body responds to these stimuli by attempting to increase rate and the depth of respiration. The volume of respiration may be limited by other factors such as partial collapse of the lung due to pneumothorax, hemothorax, actual lung destruction, obstruction of alveoli by pulmonary edema and secretions, painful splinting of the respiratory muscles, and instability of the chest wall due to multiple rib fractures. Increasing the rate of respiration provides little benefit because of the poor volume of exchange. Most of the air motion takes place within the dead air space which has been tremendously increased by the paradoxical motion of the chest wall. To improve ventilation and relieve the hypoxia and hypercarbia that initiate a lethal chain of events, the chest wall must be stabilized. Traction devices may be tried to relieve this paradoxical motion so that the patient can adequately ventilate himself, or adequate ventilation must be provided for the patient by the proper mechanical respirator. Fractures of the ribs and sternum, or costochondral separations, producing only minor degrees of chest wall instability, can be controlled by the usual methods of overhead traction with screws, wires, pins, or tongs.

When the chest wall is badly crushed, particularly bilaterally, adequate stabilization is usually impossible by these traction methods. These patients must be provided with adequate ventilation by mechanical means. The idea of providing intermittent positive pressure oxygen to cases with ventilatory insufficiency is not new. Over 400 years ago, Vesalius of Holland (1542)[14] insufflated gases into the trachea by means of a simple device similar to the fireside bellows. At the turn of the twentieth century, the pioneers of thoracic surgery were using a Fell-O'Dwyer foot bellows apparatus, the positive pressure cabinet of Brauer of Hamburg, and the negative pressure cabinet of

Sauerbruch, the forerunner of the Drinker respirator More recently, there have been many reports using the modern designed respirators of Engstrom, Blease Monaghan, Huxley, Bennett, Emerson, Jefferson, VanBergen, Morch, and many others[15-21] for ventilatory maintenance of apneic patients, particularly those suffering from bulbospinal poliomyelitis These machines have also been used on patients suffering from postresection pulmonary insufficiency and acute systemic tetanus

During World War II, the value of assisted ventilation was realized in crushing injuries of the chest Positive pressure oxygen was administered by use of a tightly fitting face mask or provided directly through an endotracheal tube connected to an oxygen bag A Drink [illegible] respirator was sometimes used to transport the patients to a treatment [illegible] The value of this type of treatment has not been fully appreciated [illegible] in his illuminating report, described the pressure relationships [illegible] tion necessary to correct the paradoxical motion of a fractured ch [illegible] observed the beneficial results of intermittent oxygen therapy durin [illegible] gency phase of treatment and realized that this must be continued until [illegible] chest had healed He devised a simple and inexpensive apparatus to [illegible] tive pressure oxygen through the tracheostomy tube He found th [illegible] te gas exchange could often be maintained on a 4 cm water pre [illegible] al between inspiration and expiration so that the intratracheal [illegible] fell below atmospheric pressure on inspiration, and would raise [illegible] above atmospheric pressure on expiration We have used Jense [illegible] with good results when the patient had active respiratory move [illegible] re was no associated brain damage

In many cases, adequate ventilat [illegible] maintained with a demand flow apparatus and it is not feasible [illegible] spiratory resistance above 4 cm of water because of the deleteri [illegible] circulation Demand flow respirators are not adequate for man [illegible] injuries because muscle, nerve, and brain damage may block the patient [illegible] bility to [illegible] mand" Most of the other common respirators now being used are cycled by either time or pressure and operate to deliver a certain pressure Pressure differentials will vary from individual to individual and often in the same individual from time to time, depending on the variations in the resistances in the pulmonary tree These resistances are the flow of gases through the tracheobronchial tree, the frictional resistance between tissues, and the resistance due to the elasticity of the chest wall and lungs often referred to as "pulmonary compliance" To maintain a patient in a steady, and even predetermined, physiologic level, the minute volume must be maintained at a constant, while the pressure differentials are allowed to fluctuate, depending on the elastic properties of the lungs and chest wall and frictional resistance in the tissues and the airway

Morch Piston Type Respirator The Morch respirator was found t [illegible] particularly adaptable for the treatment of patients with severe chest in [illegible] (Fig 6) This machine was first designed and used [illegible] while in Copenhagen[12] It consists of a piston type [illegible] motor and is designed to give a large stroke volume (Fig. 7). The stroke volume is adjustable from 0 to 3,600 c.c. Fresh air, or air-oxygen mixture, is pumped from the cylinder across a humidifier to the tracheostomy. A specially designed "check-valve" is interposed in the system near the tracheostomy tube so that exhalation takes place as soon as the desired stroke volume has been delivered (Fig. 8). The apparatus is ruggedly constructed so that mechanical failures have been nil. A hand-bellows has also been incorporated in the machine so that ventilation can be carried out in case of electrical power failure or when transporting the patient (Fig. 9).

Although it first seemed unreasonable to use an uncuffed tracheostomy tube, the advantages of the uncuffed tube are now obvious.[21] It was first used by one of us (E. T. M.), in 1951.[23]

The Cuffed Tracheostomy Tube.—The use of the cuffed tracheostomy tube (Fig. 10) is disadvantageous in many respects, and it is said to be attended "by all sorts of complications."[24] (1) The soft rubber tracheostomy tube with inflatable tube is much more difficult to insert into the right place in the trachea than the silver tube. The cuffed tube may go into the loose connective tissue outside the trachea; it may not be inserted far enough; or it may be inserted too far so as to enter the right main bronchus so as to obstruct the right upper lobe orifice. (2) The cuff offers resistance on insertion, and may rupture or be dislocated during insertion. (3) The cuff is unreliable and treacherous because it is difficult to keep inflated and the inflated cuff presses against the tracheal mucosa and may cause trauma or even necrosis.

The Uncuffed Tracheostomy Tube.—The uncuffed tracheostomy tube for intermittent positive pressure breathing has been used by us (Fig. 11). It proved satisfactory if a high stroke-volume respirator was used, enabling one to compensate for the leaks. The uncuffed tracheostomy tube is now used routinely for all cases requiring ventilation by tracheostomy. It has been used continuously for periods up to thirteen months in cases of respiratory paralysis due to poliomyelitis. The leak up through the larynx has proved desirable as a safety device against excessive pressures in the lungs and will prevent secretions from entering the trachea by blowing them from the pharynx up toward the mouth where they are easily accessible to the nursing staff.

Care of Tracheostomy.—For tracheostomy, an ordinary Chevalier Jackson silver tracheostomy tube has been modified (E. T. M.) with two swivel joints so that the patient may move his head without impingement of the tube on the trachea.[25] A screw cap allows access for suctioning without actually disconnecting the attached tubing from the respirator.

Proper humidity can usually be maintained by filling the humidifier in the respirator with 5 per cent alcohol-water solution. Additional humidity can be used by inserting a Hi-flow nebulizer in the system. In some cases, distilled water will be sufficient for aerosol. In other cases, bronchial secretions may be viscid, and large plugs or crusts, life-threatening. Diluted Alevaire (1:4)

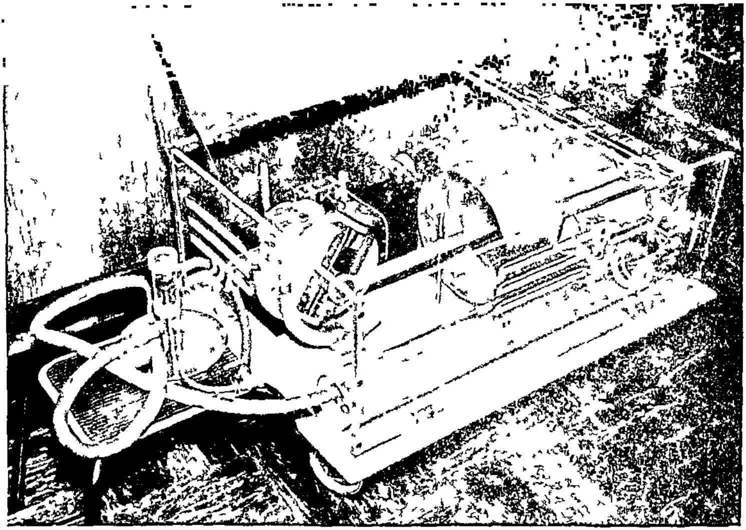


Fig 6—Morch piston respirator connected to plastic check valve and tracheostomy tube

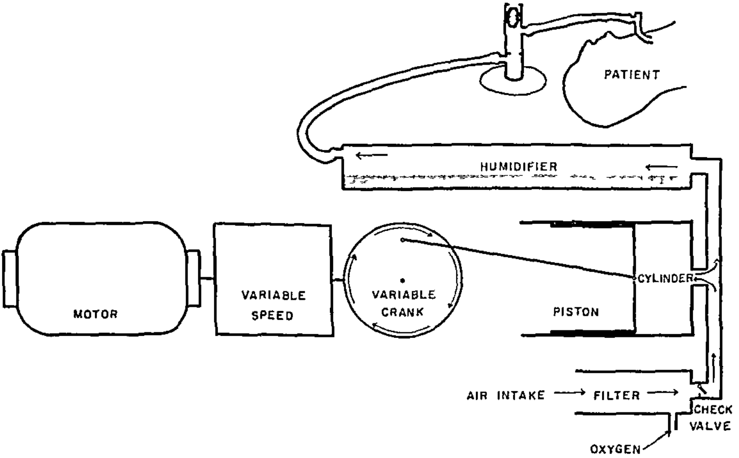


Fig 7—Diagram showing the principles of the Morch piston respirator

may be used effectively as a detergent and occasionally diluted Tryptar enzyme digestant is necessary. Bronchoscopic aspiration through the tracheostomy can be used as indicated. In chest injuries, tracheobronchial suctioning must be carried out every 15 to 30 minutes because of the large volumes of secretions. To prevent further contamination of the airway, a sterile catheter

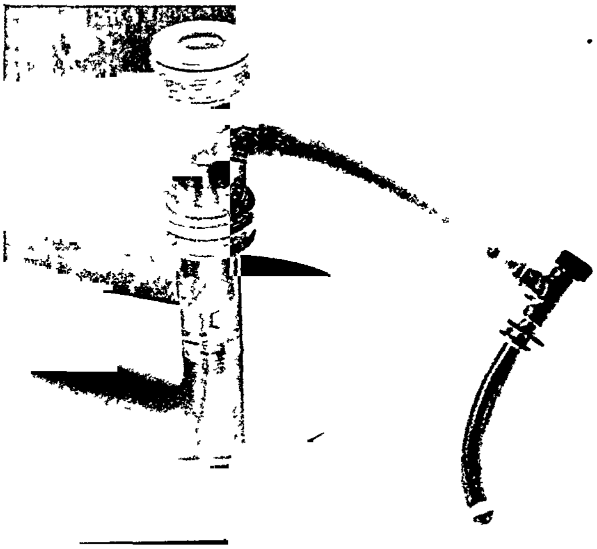


Fig. 8.—Morch plastic exhalation valve and swiveled, uncuffed, silver tracheostomy tube.

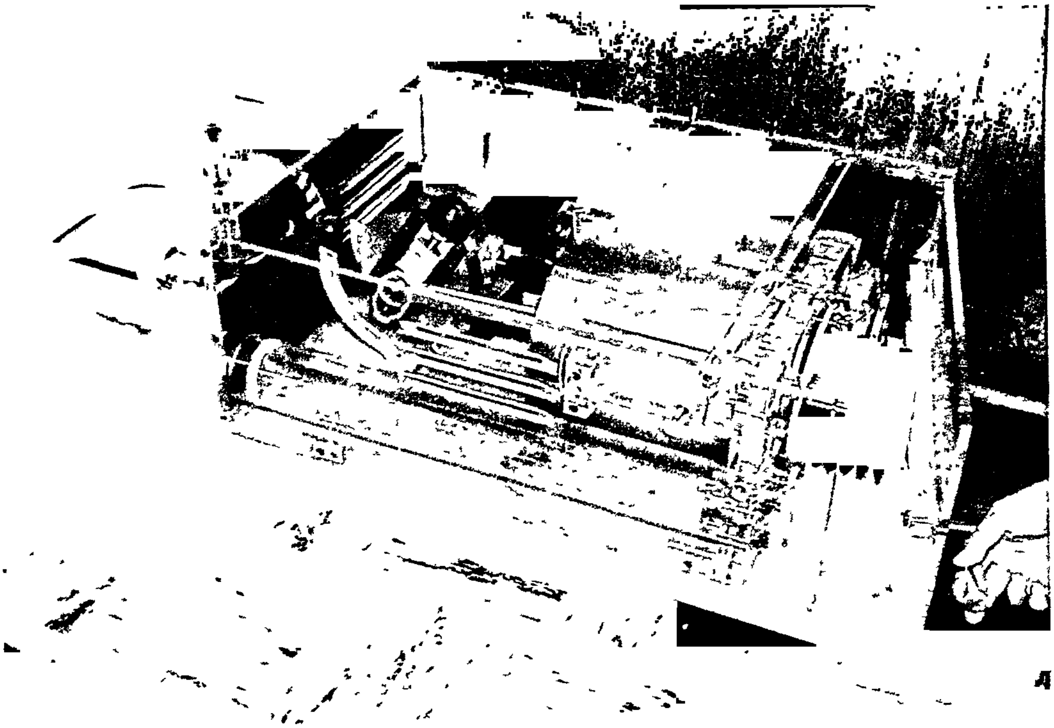
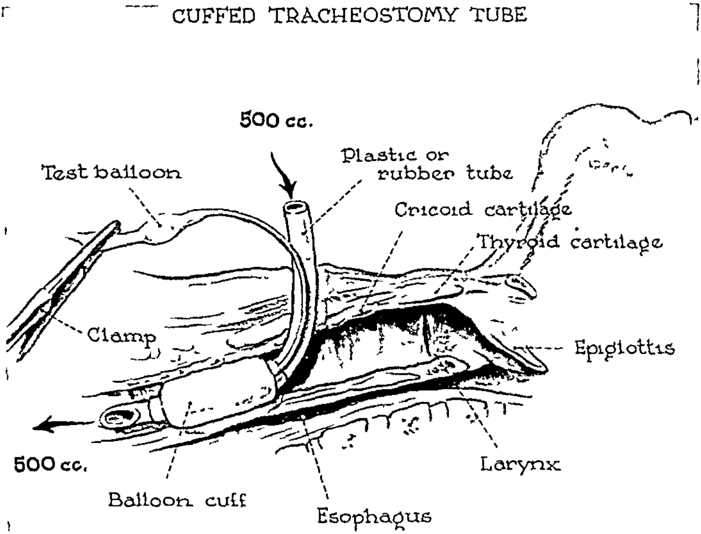


Fig 9—Morch respirator showing emergency hand bellows for use in case of electrical power failure or transportation of patient.



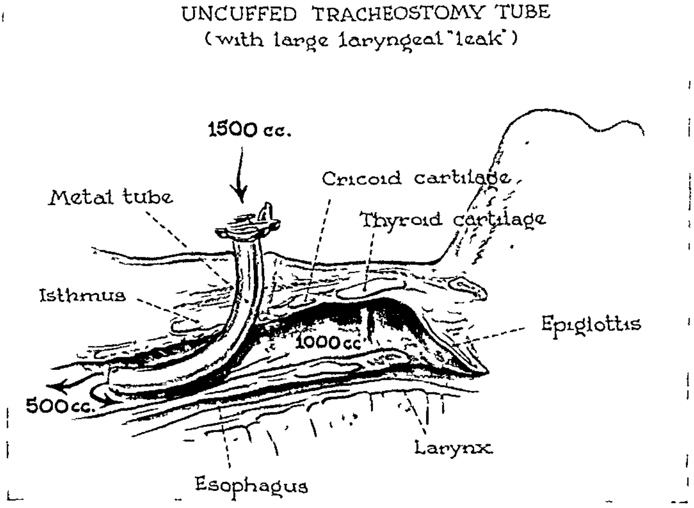


Fig. 10.—Cuffed tracheostomy tube must be airtight for pressure cycled respirators.

Fig. 11.—Uncuffed tracheostomy tube delivers adequate ventilation if respirator stroke volume is sufficient to compensate for laryngeal leak.

should be used with each aspiration. The Coudé curved-tip catheter is the easiest to insert into both the right and left bronchi by merely turning the tip in the correct direction.

Cultures and antibiotic sensitivities are taken on bronchial secretions at appropriate intervals to determine the effective antibiotics to be used parenterally and topically to inhibit tracheobronchial and pulmonary infection.

Proper Respirator Pressure Profile.—Cournand and Motley and their associates[26] found that cardiac output was not decreased with intermittent positive pressure respiration provided that the expiratory phase was slightly longer than the inspiratory phase and when the expiratory pressure was allowed to drop to that of the atmosphere. In other words, normal cardiac output depends more on the type of pressure profile in terms of the length of inspiratory and expiratory phases and the mean intratracheal pressures rather than the peak intratracheal pressure. A proper pressure profile allows for the adequate recovery of circulation during expiration so that blood flow remains constant even over wide ranges of intratracheal pressures. Inspiration is accomplished with a short blast of air occupying only one-third of the respiratory cycle time. The peak inspiratory intratracheal pressures are usually 30 mm. Hg or less. By balancing the stroke volume and rate of respiration against the patient's tracheobronchial resistance and pulmonary compliance a proper pressure profile can be obtained for each patient.

The Maintenance of Adequate Alveolar Ventilation.—There will be adequate oxygenation of the blood when air or gas mixtures have oxygen tensions of 100 mm. Hg or greater. This tension is easily obtained. Therefore, ventilation should be regulated according to the amount of carbon dioxide to be removed.[27] Because of serious alterations that can occur in acid-base and electrolyte balance with abnormal concentrations of carbon dioxide, it is necessary to keep the concentration of this gas within certain limits. It has been found that respiratory acidosis has far more serious consequences than mild respiratory alkalosis; therefore, it is logical to keep the patient in normal balance or even in slight respiratory alkalosis. The Radford nomogram can be used to calculate the minute ventilatory volume on the basis of each patient's metabolic demands.[28] We have found it simpler to keep the body in a state of slight respiratory alkalosis so that we can call upon the brain's respiratory center to help monitor the controls of the mechanical ventilator. By adjusting the stroke volume and rate of the respirator so as to keep the alveolar CO_2 tension just at the level to render the patient apneic we are able to take advantage of this delicate monitoring system. Should the patient benign to make spontaneous respiratory efforts, stroke volume can be slightly increased to render him again apneic. This volume of ventilation should be carefully titrated so as not to hyperventilate the patient massively. Serious deviations in blood chemistry due to hyperventilation can be avoided by checking the pH and CO_2 of the venous blood once or twice daily. If the patient's respiratory center is depressed by associated brain damage, more frequent analysis of pH and CO_2 may be necessary. Protein and electrolyte levels should be properly maintained by appropriate studies and therapy.

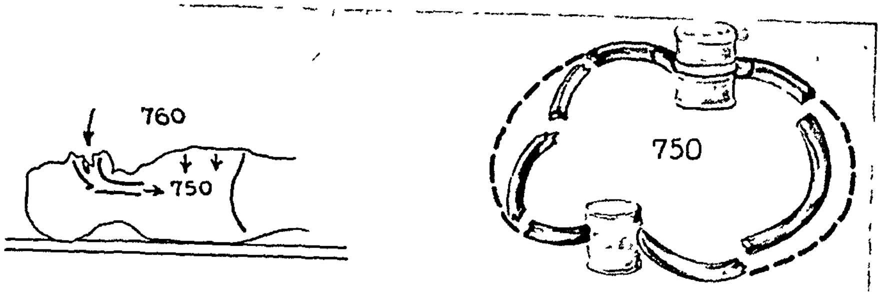
Rationale of Hyperventilation Therapy.—Although mechanical respirators have had wide application in a variety of pathologic conditions having ventilatory insufficiency, and even in chest injuries, we believe that we are the first to recommend prolonged mechanical *hyperventilation* to produce alkalotic apnea as a therapeutic modality in severe crushing injuries of the chest.[10, 29]

The manner in which hyperventilation counteracts paradoxical respiration and overriding fractured ribs can be explained as a combination of two factors, mechanical and biochemical (Fig. 12).

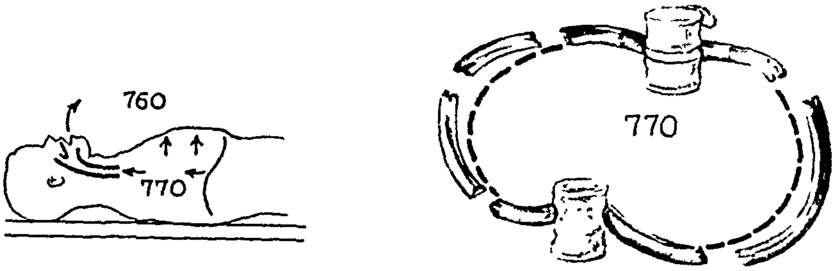
The mechanical factor is as follows: During *active inspiration,* as the diaphragm descends, the intrathoracic pressure decreases to subatmospheric. The extrathoracic atmospheric pressure, now being greater, pushes the traumatically softened thorax inward and paradoxical motion and overriding of the ribs results. During *active exhalation* the reverse takes place. The intrathoracic pressure is now above the extrathoracic atmospheric pressure and the fractured parts of the bony thorax are pushed outward.

During *passive* (mechanical) *inspiration,* the air is automatically pushed into the lungs under a pressure which exerts a gentle, evenly distributed outward push on all of the softened parts, holding them in their normal position. During *passive exhalation,* the intrathoracic pressure drops toward room pressure so that the inside push gradually diminishes. Because the patient is apneic, no voluntary diaphragmatic action occurs and consequently, no negative intrathoracic pressure develops to produce paradoxical motion. In this way, the alternating positive and subatmospheric pressure during active respiratory efforts has been replaced by a fluctuating positive pressure. The only rib motion is in their normal arcs while they passively ride on this cushion of air as the lungs gently, and passively, expand and contract. All paradoxical motion with overriding and grinding of broken rib ends is stopped by this "internal pneumatic stabilization."

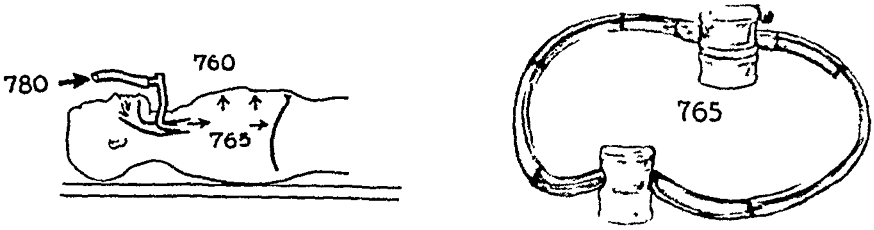
The Biochemical Factor Is as Follows.—During hyperventilation, carbon dioxide is washed out of the lungs. The CO_2 drops in the alveolar air, in the blood, and in the respiratory center, and active respiration ceases. Hypoxia and hypercarbia, having previously aggravated pulmonary and cerebral edema, are now corrected and this trend reversed. The vicious cycle is thus broken by adequate alveolar ventilation. The chest wall now follows the passive variations in pressure produced by the respirator, and paradoxical movements disappear. When a patient with an injured chest is left to breathe by his own voluntary efforts, ventilation will be insufficient and some degree of asphyxia will develop with resultant excitement, restlessness, and confusion. When mechanical ventilation is carried out, hypoxia disappears and with it the central stimulation. If sufficient carbon dioxide is blown out, a mild sedation has been found in most patients. The respiratory musc [illegible] cause th



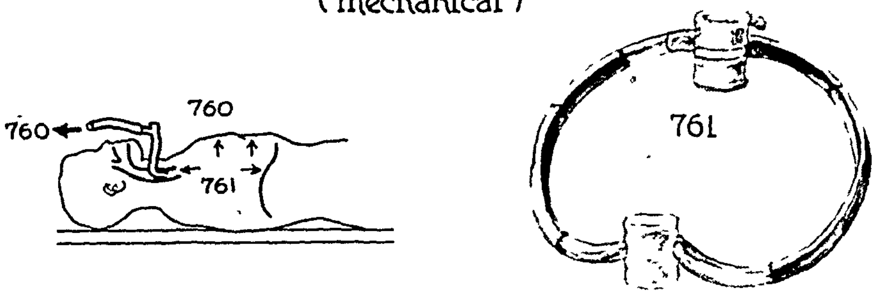
A. ACTIVE INSPIRATION



B. ACTIVE EXPIRATION



C. PASSIVE EXPIRATION
(mechanical)



D. PASSIVE EXPIRATION
(mechanical)

Fig. 12.—*A* and *B* illustrate pressure relationships with active voluntary respiratory efforts causing paradoxical motion of chest wall and overriding and grinding at rib ends.

C and *D* illustrate passive (mechanical) ventilation. Chest wall and ribs ride passively up and down in their own arcs as the lung gently inflates and deflates. All paradoxical motion with overriding and grinding of broken rib ends is stopped by this "internal pneumatic stabilization."

work is done for them and the result is that the patient rests and may even go to sleep. Sedatives may be given as desired for the fear of depression of the respiratory center is now obviated by the mechanical respirator.

A deterrent to the application of prolonged passive mechanical hyperventilation has been the time-honored fear of the adverse effects of the "active hyperventilation syndrome" as seen in hysteria, volunteers, and metabolic acidosis.[30]

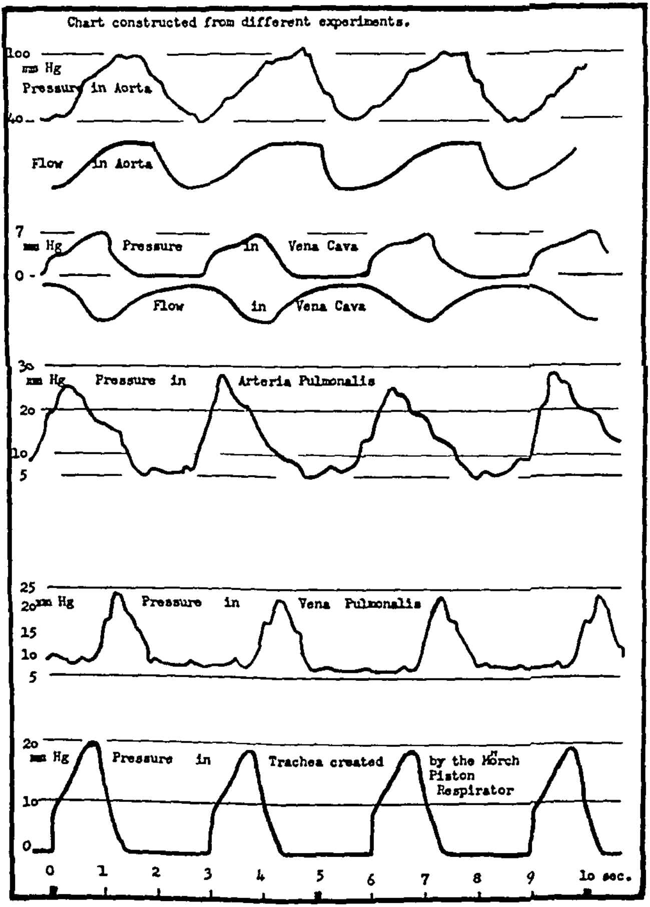


Fig. 13.—This graph shows that pressures and flows in both systemic and pulmonary vessels vary synchronously with the intratracheal pressure. Cardiac output remains practically normal.

These symptoms of tetany, convulsions, unconsciousness, and even death, however, appear to occur only in active hyperventilation. None of these ill effects have been seen in our patients with crushed chests using continuous passive hyperventilation to produce mild respiratory alkalosis for periods of more *than a month*. Mechanical ventilation has been carried out without adversity in patients for over thirteen months.

Another deterrent to this new method of treating crushed chests has been the numerous references regarding deleterious response to the circulation to intermittent positive pressure insufflation.[31-38] Circulatory changes caused by varying the endotracheal pressures have been studied by us in man and in several experimental animals (dog, rabbit, guinea pig, and bat) (Fig. 13). The circulation has not been significantly disturbed when the pressure within the trachea has the correct amplitude, timing, and mean pressure.

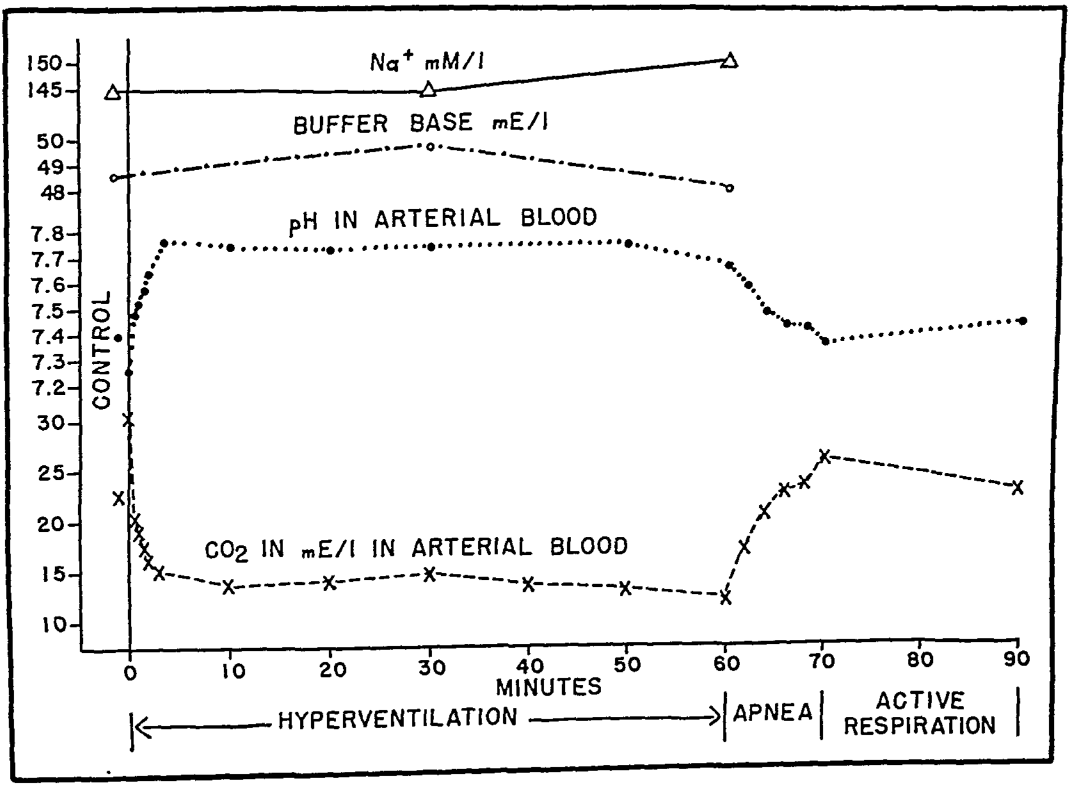


Fig. 14.—Chemical changes in dog experiment with massive hyperventilation.

Changes in blood chemistries have been carefully studied and no undesirable symptoms were found in dogs vigorously ventilated to produce marked respiratory alkalosis (Fig. 14). The chemical changes into and out of respiratory alkalosis took place in a few minutes. Blood chemistries were carefully studied on humans treated on the Mörch respirator by mild respiratory alkalosis and these studies revealed that no serious deviations occurred in pH, CO_2, and electrolyte balance (Fig. 15).

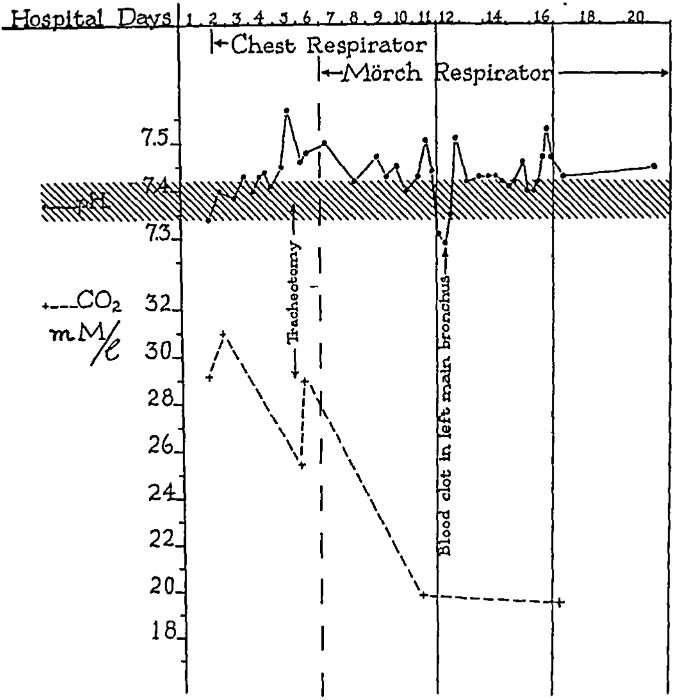


Fig. 15—Chemical changes in a patient on prolonged mechanical hyperventilation.

SUMMARY AND CONCLUSIONS

1. A new method of treatment of severe crushing injuries of the chest is presented with the use of continuous hyperventilation by means of intermittent positive endotracheal insufflation to produce alkalotic apnea.

2. The most striking benefit of this mechanical hyperventilation treatment is that it is safe and allows the survival of patients with seemingly hopeless prognosis.

3. Other benefits are: correction of paradoxical motion of the chest wall; removal of hypoxia and hypercarbia; absence of pulmonary edema; less sedation is required; no serious deviations in blood chemistry with prolonged mild respiratory alkalosis; no measurable circulatory defects; prompt return of blood chemistries and physiologic responses to normal with cessation of hyperventilation; and no late ill effects.

4. Continuous mechanical ventilation should find a much wider range of application where there is loss of integrity of the chest wall (crushing in-

juries); infections (poliomyelitis, tetanus, etc.); muscle disease (myasthenia gravis, etc.); trauma to the brain (head injuries, postoperative neurosurgical conditions, cerebral vascular accidents); respiratory depression (industrial poisons, suicide, overdosage of medications, and anesthetics); and in ventilatory insufficiency following pulmonary resection. Many of these patients die, not of their primary pathology, but from complications arising from decreased pulmonary ventilation.

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38 Ankeney, J L, Hubay, C A, Hackett, P R, and Hingson, R A The Effect of Positive and Negative Pressure Respiration on Unilateral Pulmonary Blood Flow in the Open Chest, Surg, Gynec & Obst 98 5, 1954

DISCUSSION

DR HELGE WULFF, Malmo, Sweden —The excellent equipment so well demonstrated here by Dr Morch and his collaborators is no doubt a good contribution to the treatment of risky pulmonary tuberculosis patients operated on with segmental resections and lobectomies, and especially of polio cases Dr Trier Morch has demonstrated the equipment in Scandinavia and, in Sweden, we have used it in a slightly modified type with great success I have listened to the demonstration with great interest

DR B H RAMSAY, Los Angeles, Calif —I wish to congratulate Dr Avery, Dr Morch, and Dr Benson on their very interesting paper I think this is something we all need to learn to do and obtain the equipment to do so In general, treatment of the crushed chest is unsatisfactory, as exemplified by this patient Two years ago, when 65 years of age, she sustained anterior and posterior fractures of all twelve left ribs When she survived, everyone concerned was pleased, but the rib fractures, although all healed, had caused displacement and reduction in the left hemithoracic volume by at least 50 per cent There was little ventilation in the compressed left lung One year later, a second accident, involving only two of the upper ribs on the right side and a very small pulmonary hematoma, almost resulted in her death as a secondary upper wall atelectasis occurred, due to clotted blood Only tracheostomy and constant care preserved her Any nontraumatic right sided disease such as pneumothorax, or atelectasis, or pneumonia, or even an infarct, would have been similarly serious

Long ago, surgeons were satisfied if a broken bone healed Then the disadvantages of nonunion and shortening were appreciated Accurate reduction and complete return of function are now the expected goal This must be our idea also in management of the crushed chest Because of associated injuries, old age and debility, and the need to get people out of bed and back to work, it is not satisfactory to employ routinely balanced traction in a bed frame During the phase of shock, it is not practicable to wire the fractured ends front and back I believe that one can reduce the displaced section of the chest by one or more temporary pericostal or peristernal traction sutures, of wire or other material, placed at the center of the flail by direct surgical attack under local anesthesia, attaching these to an external splint similar in all respects to that commonly employed juries); infections (poliomyelitis, tetanus, etc.); muscle disease (myasthenia gravis, etc.); trauma to the brain (head injuries, postoperative neurosurgical conditions, cerebral vascular accidents); respiratory depression (industrial poisons, suicide, overdosage of medications, and anesthetics); and in ventilatory insufficiency following pulmonary resection. Many of these patients die, not of their primary pathology, but from complications arising from decreased pulmonary ventilation.

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DISCUSSION

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DR. B. H. RAMSAY, Los Angeles, Calif.—I wish to congratulate Dr. Avery, Dr. Mörch, and Dr. Benson on their very interesting paper. I think this is something we all need to learn to do and obtain the equipment to do so. In general, treatment of the crushed chest is unsatisfactory, as exemplified by this patient. Two years ago, when 65 years of age, she sustained anterior and posterior fractures of all twelve left ribs. When she survived, everyone concerned was pleased, but the rib fractures, although all healed, had caused displacement and reduction in the left hemithoracic volume by at least 50 per cent. There was little ventilation in the compressed left lung. One year later, a second accident, involving only two of the upper ribs on the right side and a very small pulmonary hematoma, almost resulted in her death as a secondary upper wall atelectasis occurred, due to clotted blood. Only tracheostomy and constant care preserved her. Any nontraumatic right-sided disease such as pneumothorax, or atelectasis, or pneumonia, or even an infarct, would have been similarly serious.

Long ago, surgeons were satisfied if a broken bone healed. Then the disadvantages of nonunion and shortening were appreciated. Accurate reduction and complete return of function are now the expected goal. This must be our idea also in management of the crushed chest. Because of associated injuries, old age and debility, and the need to get people out of bed and back to work, it is not satisfactory to employ routinely balanced traction in a bed frame. During the phase of shock, it is not practicable to wire the fractured ends front and back. I believe that one can reduce the displaced section of the chest by one or more temporary pericostal or peristernal traction sutures, of wire or other material, placed at the center of the flail by direct surgical attack under local anesthesia, attaching these to an external splint similar in all respects to that commonly employed now in the operation for correcting pectus excavatum. It can be placed laterally or anteriorly. Copper wire, if used, will not easily break or bend, and this can be passed through polyethylene tubing to avoid tissue reaction. I believe emphasis should be placed on retaining the full circumference of the chest and full function thereafter in all instances of chest injury.

DR. N. K. JENSEN, Minneapolis, Minn.—I would like to congratulate Dr. Avery, Dr. Trier Mörch, and Dr. Benson on this excellent contribution. I propose to discuss very briefly the management of chest injuries and particularly to point out that the type and degree of injury are what should condition the method of management.

We believe that the most essential treatment, the most essential maneuver in management of chest injury, particularly a crushing injury of the chest, is a tracheostomy. Many patients with severe chest injuries will do well with a simple tracheostomy. The tracheobronchial secretions can be managed by effective aspiration. The resistance to flow of the respiratory exchange is reduced enough by tracheostomy so that paradoxical motion will subside and the patient will be able to manage his own exchange very well.

The group unable to maintain adequate exchange because of persistence of a flail chest wall after tracheostomy can be managed by simple continuous positive pressure with about 2 cm. of water pressure maintained at all phases of respiration. This maneuver converts ventilation into active expiration while passive inspiration is provided by the positive pressure. In other words, the abdominal muscles take over and exhale against the positive intrapulmonary pressure. The thoracic cage is held steady in an almost full inspiratory position and paradoxical motion stops.

Everything goes well with continuous positive pressure unless one of two situations arises. If tachypnea develops or is present, either because of head injury or respiration too limited in depth because of loss of lung elasticity as in emphysema or for other reasons, then inspiration must be deepened to slow the rate and this requires assistance by mechanical ventilation. Likewise, if abdominal complications develop which result in splinting of the abdominal musculature in association with a flail chest, both mechanisms of respiration are seriously crippled and mechanical ventilation is required.

In summary, I think we should all appreciate the fact that the patient with a severely crushed chest or a fixed thoracic cage who also suffers from a paralyzed or immobilized abdominal musculature must have mechanical ventilation to survive.

DR. JOHN H. GIBBON, Jr., Philadelphia, Pa.—I think we ought to recognize that Avery and Mörch and Benson have given us a very significant and revolutionary contribution toward the surgery of trauma in these difficult cases. All of us, of course, who have been interested in methods of mechanical ventilation have used them during operative procedures and on patients whose respiratory muscles are paralyzed, and have been able to maintain respirations for days by this method. This is the first time, to my knowledge, that I have heard and seen the beautiful results obtained in the stabilization of a flail chest by mechanical ventilation. It seems to me this should have far-reaching consequences in the planning for mass injuries. I hope that members of this Association, and others who are in a position to take care of patients with traumatic injuries of the thorax, will try this method, so that next year a much wider experience can be reported to confirm these very interesting and exciting results.

DR. GEORGE N. J. SOMMER, JR., Trenton, N. J.—I agree that this has been really a splendid paper. I want to mention particularly that this type of injury is to my mind very much on the increase even in my own practice. I came down here yesterday and on the way I passed four automobile accidents of a serious nature. Another point, I chased cars all the way down although I was driving pretty fast. In my opinion, with the speed of travel at the present time, we are going to find more and more drivers of automobiles seriously injured with crushing chest injuries as they crash against steering wheels. Twenty or 25 years ago people were talking about head injuries. The drivers in those cases were usually protected by their feet on the brakes and their grasp on the steering wheel, with the car going 40 or 50 miles an hour At the present time, 60 and 70 miles per hour seems to be the usual rate of speed The drivers are no longer given that protection I think that is the reason why there is, and is going to be, such a marked increase of these serious injuries Certainly they are serious and the work done today and shown today shows a method of saving the most seriously injured

I think Dr Gibbon made one mistake,* although he does not make very many But, in the case of mass injuries, these people are going to die There will never be enough equipment for what he has in mind, or enough personnel to save people if there are thousands and thousands of casualties The people less severely injured will be saved, but I am afraid that neither he nor I nor anybody else can save these very seriously injured people with a great many injuries

DR PETER V MOULDER, Chicago, Ill —Dr Morch and Dr Benson have asked me to show you a movie demonstrating the effect of positive pressure on the circulation The small vessels in the bat wing are filmed through a microscope during periods of varying pressures in the trachea Air is moved via an intubated tracheostomy Circulation is first demonstrated during normal respiration, showing a steady flow in the veins and arterioles With prolonged high, positive pressure there is marked slowing and reversal of flow in the arterioles With the use of a high pressure of short duration and a negative phase, circulation is nearly normal Arteriolar flow slows for a short moment at the peak pressure only

DR EDWARD E AVERY, Chicago, Ill (Closing) —I wish to acknowledge my sincere gratitude to my co authors, Drs Morch and Benson It has been an unusual pleasure to have the close cooperation of two departments of both Northwestern and Chicago Medical Schools collaborating on this important clinical problem The Morch respirator used on these patients represents the culmination of many years of his research in this field Dr Morch's imagination is boundless Who else would think of intubating a bat! It does point out that this principle of mechanical ventilation can be applied to a 70,000 gram human being or a 5 gram bat

With regard to Dr Roe's paper on premature infants with hypoplastic lungs, we are adapting the Morch respirator for use in these cases We feel as Dr Potts does, that these babies must be kept alive long enough to let their underdeveloped lungs grow We believe that we may be able to provide adequate air exchange to support life by hyperventilating whatever little normal lung tissue is present

I want to thank all the discussants for their contributions It is our hope that this mechanical hyperventilation therapy will find wide application for patients with serious chest injuries

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*Dr Gibbon later told the discussant that he was speaking of civilian disasters with perhaps 100 or 200 injured persons rather than of an atomic attack with thousands of injured.

TRAUMATIC RUPTURE OF THE LEFT-MAIN BRONCHUS SUCCESSFULLY REPAIRED ELEVEN YEARS AFTER INJURY

DANIEL E. MAHAFFEY, M.D. (BY INVITATION), OSCAR CREECH, JR., M.D.,
HOLLIS G. BOREN, M.D. (BY INVITATION), AND MICHAEL E. DEBAKEY, M.D.
HOUSTON, TEXAS

RUPTURE of one of the major bronchi is now regarded as a relatively common complication of severe trauma to the thorax. Although the condition was diagnosed at necropsy more than fifty years ago,[1, 22, 30, 44] it was not recognized that this injury was compatible with survival until the report of Krinitzke in 1928.[26] Subsequently, Jones and Vinson[21] made the diagnosis clinically, the site of injury being visualized at bronchoscopy. In reporting his experiences with injuries of the chest during World War II, Sanger,[41] in 1945, described 2 cases of traumatic wounds of major bronchi in which he was able to achieve a successful closure. It was not until 1948, however, that Griffith[15] reported the first case to be treated successfully by excision of the strictured segment of bronchus and restoration of bronchial continuity. Operation was performed about eight months after injury and was preceded by several unsuccessful attempts to dilate the stricture. Bronchial anastomosis was performed with No. 38 stainless steel wire, reinforced with fascia. Bronchogram following operation was reported as normal and the vital capacity increased from 2,100 c.c. before operation to 2,700 c.c. eight months after operation.

Since that time many reports have appeared of successful surgical correction of this type of lesion, two hours to fifteen years following injury.[10-12, 16, 32, 35, 37, 38, 40, 42, 43, 45] The most notable case is that recorded by Samson and Evans[40] in which complete rupture of the right main bronchus was successfully corrected, fifteen years after injury.

In spite of the large number of instances of operative treatment of this condition, there is a paucity of data regarding changes in lung function resulting from the injury and from its correction.[15, 40, 48] Recently we have successfully treated a case of traumatic rupture of the left main bronchus eleven years after injury. Pulmonary function studies were made before and on two occasions after operation. Because of its unusual clinical features and the interesting data it affords regarding pulmonary function, this case is reported.

CASE REPORT

W. E., a 32-year-old Negro man, was admitted to the surgical service of the Houston Veterans Administration Hospital, Aug. 31, 1955, with the complaint of exertional dyspnea of eleven years' duration. Dyspnea had appeared following an injury on Dec. 26, 1943,

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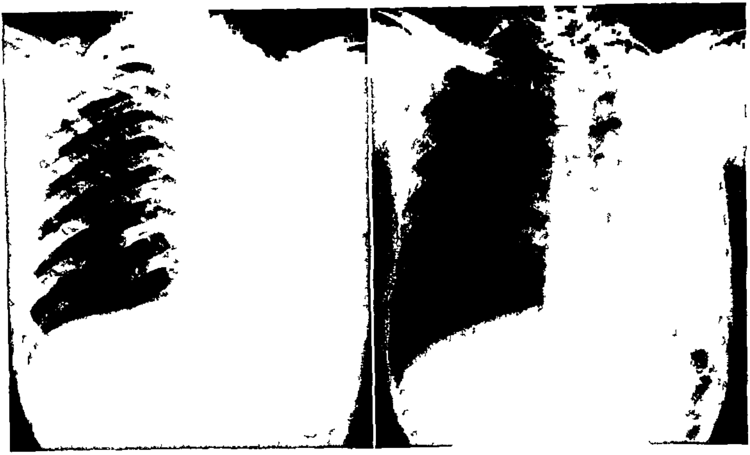
From the Cora and Webb Mading Department of Surgery and the Department of Medicine, Baylor University College of Medicine, and the Veterans Administration Hospital, Houston, Texas.

Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.



A

B

Fig 1.—*A*, Roentgenogram of the chest two months after injury showing a homogeneous density of the left hemithorax overdistention of the right lung and displacement of mediastinal structures to the left *B* Roentgenogram of the chest approximately eleven years later reveals an increase in volume of the right lung and further movement of the mediastinum to the left

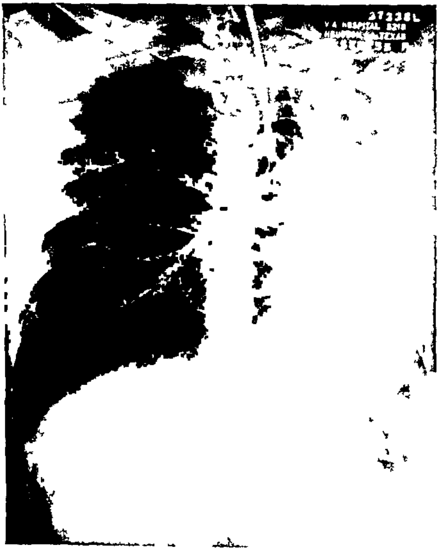


Fig 2.—Bronchogram made prior to operation showing the left n
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Daniel E. Mahaffey, M.D. (by invitation), Oscar Creech, Jr., M.D., Hollis G. Boren, M.D. (by invitation), and Michael E. DeBakey, M.D.
Houston, Texas

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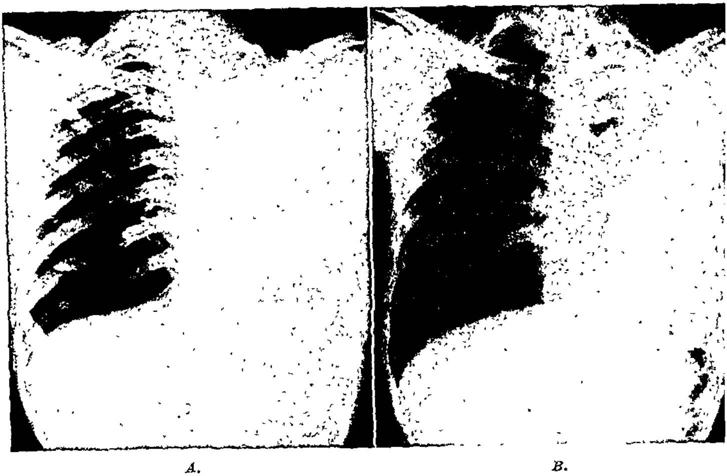

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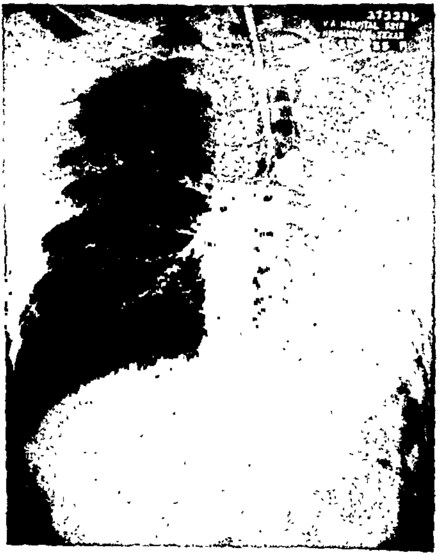

Fig. 2.—Bronchogram made prior to operation showing the left main bronchus ending blindl The bronchial pattern of the overdistended right lung is relatively

while in the Navy. The patient fell from a tractor on which he was riding and was run over by the front wheel of an attached trailer. Fractures of the left first rib, both rami of each pubic bone, and an indeterminate injury to the left chest resulted. At the time of injury the patient was in mild shock. There were dullness and absent breath sounds over the left side of the chest and deviation of the trachea to the left. However, hemoptysis, pneumothorax, and emphysema were conspicuously absent. Thoracentesis was performed on one occasion and an unknown quantity of blood removed. Roentgenograms of the chest following injury revealed opacification of the left hemithorax and marked deviation of the trachea and mediastinum to the left (Fig. 1, *A*).

Approximately four months following injury, the patient was given convalescent leave and somewhat later he was discharged from the service with a diagnosis of ''atelectasis, left lung.''

Physical examination at the time of admission, in 1955, revealed a slender Negro man who breathed easily at rest. The blood pressure was 114 mm. Hg systolic and 80 mm. Hg diastolic. The trachea was deviated to the left and there was flattening of the left chest anteriorly. The apical cardiac impulse was shifted markedly to the left. Breath sounds were absent over the entire left hemithorax except parasternally and paraspinally, where tubular breath sounds were audible.

Routine laboratory studies were reported as normal. Roentgenograms of the chest revealed a marked shift of the trachea and mediastinum to the left and a homogeneous density throughout the left hemithorax (Fig. 1, *B*). A bronchogram disclosed that the left main-stem bronchus ended blindly, approximately 2 cm. distal to the carina (Fig. 2). The right lung was overdistended with a normal bronchial pattern. An electrocardiogram revealed a sinus bradycardia and an incomplete right bundle branch block. Basic pulmonary function studies showed a reduced vital capacity but a normal maximum breathing capacity (Fig. 3). Angiocardiography was performed with 70 per cent Urokon sodium, but the opacity of the left chest precluded good visualization of the vascular bed of the left lung.

On Sept. 19, 1955, operation was performed. After anesthetization but prior to operation, bronchoscopy was carried out and the left main-stem bronchus was observed to end abruptly. The bronchial pouch was lined with normal-appearing mucosa. After bronchoscopy was completed an endotracheal tube was introduced, the patient was placed in the right lateral decubitus position, and the left chest was entered through a standard posterolateral thoracotomy incision, resecting the sixth rib. The left lung was airless and lying free. The heart was almost entirely within the left hemithorax. Pleural surfaces were glistening and normal in appearance. In fact, with the exception of complete collapse of the lung and the abnormal position of the heart, there was no evidence of any morbid process having taken place. The left main bronchus was isolated and an area of complete stricture 1.5 cm. in length was found with a proximal stump of bronchus 2 cm. in length (Fig. 4). The bronchial arteries were not enlarged and the pulmonary artery and veins appeared normal. The distal portion of the stricture was excised and a large amount of clear, gelatinous material was aspirated from the distal bronchial tree (Fig. 5, *A*). It was then possible to inflate the lung easily with slight pressure from a syringe. The region of the carina was dissected next and the proximal bronchial stump amputated above the area of narrowing to gain a normal-sized lumen, free of fibrous reaction. Similarly, a ring of cartilage was excised from the distal end thus producing two lumina of almost equal size. An anterior row of interrupted No. 3-0 silk sutures was first placed, and the sutures were then tied (Fig. 5, *B*). The membranous portion was approximated in a similar fashion, all the knots being tied outside the lumen. Upon completion of the anastomosis, the anesthetist was able to inflate the lung completely without leakage of air at the suture line. It was observed that the left lung was about one third smaller than normal. The left chest was drained with two intercostal catheters and the wound was closed. The patient was then placed in a supine position and a low tracheostomy performed.

The postoperative course was relatively benign. The chest catheters were removed on the second day and the tracheostomy tube on the ninth day after operation. Because of evidence of atelectasis of the left lower lobe, bronchoscopy was performed on the fifteenth day An 8 mm. Jackson bronchoscope was passed through the anastomosis with ease and a small area of granulation tissue noted on the anteromedial aspect of the suture line All of the bronchial divisions were patent. A bronchogram performed on the seventeenth day following operation revealed slight narrowing at the suture line although all divisions of the left lung filled (Fig 6). There was slight dilatation of some of the segmental bronchi but no evidence of true bronchiectatic change There was also crowding of the bronchi compatible with the decreased volume of the lung. On the nineteenth day following operation the patient was discharged.

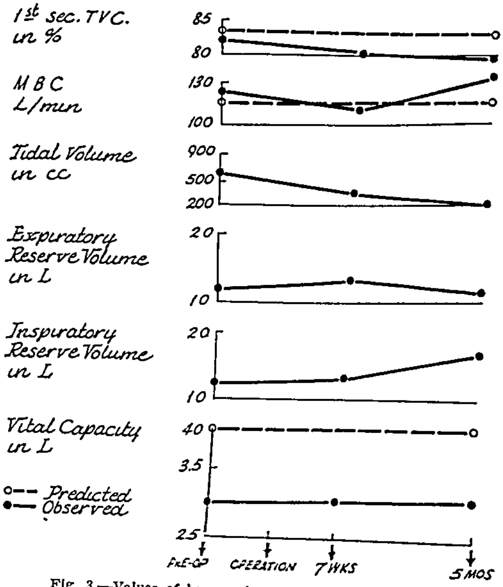

Fig 3—Values of basic pulmonary function studies

He was readmitted for pulmonary function studies at seven weeks and at five months after operation (Fig 3). At the latter admission, x rays and bronchography were repeated after the function studies had been obtained and an essentially normal bronchial tree was found with the exception of slight crowding on the left side that was again interpreted as a result of overdistention of the right lung (Fig. 7). The previously noted dilatation of some of the segmental bronchi was no longer apparent.

Since discharge from the hospital the patient has been fully employed as a truck driver. He no longer experiences dyspnea with exercise and is entirely [illegible]

DISCUSSION

Clinical Aspects—The pattern of injury[2, 16, 29, 41] resulting [illegible] of [illegible] one of the major bronchi is relatively constant. The pa

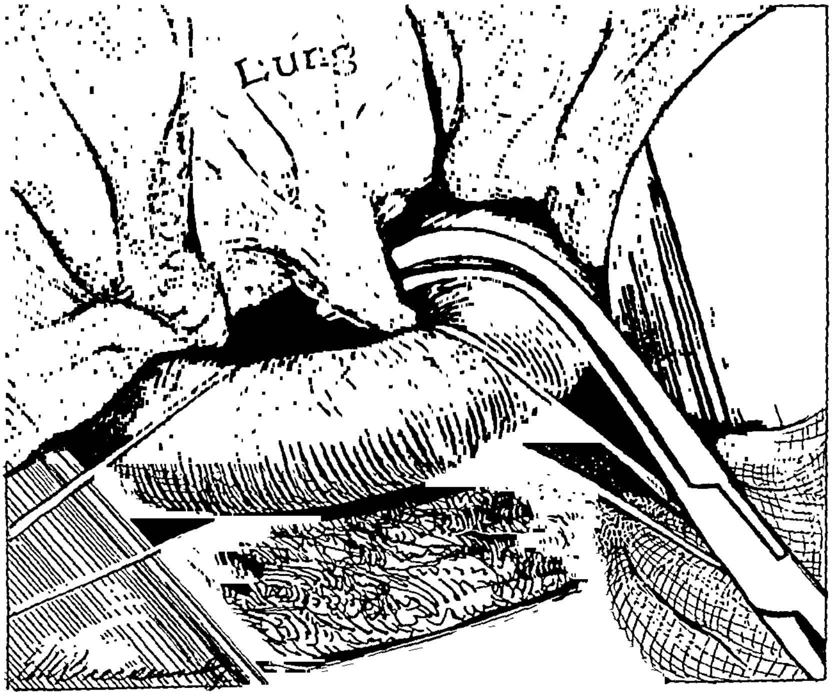

Fig. 4.—Drawing showing the location and extent of the stricture of the left main bronchus. Exposure of the stricture is facilitated by partial mobilization and retraction of the aorta.

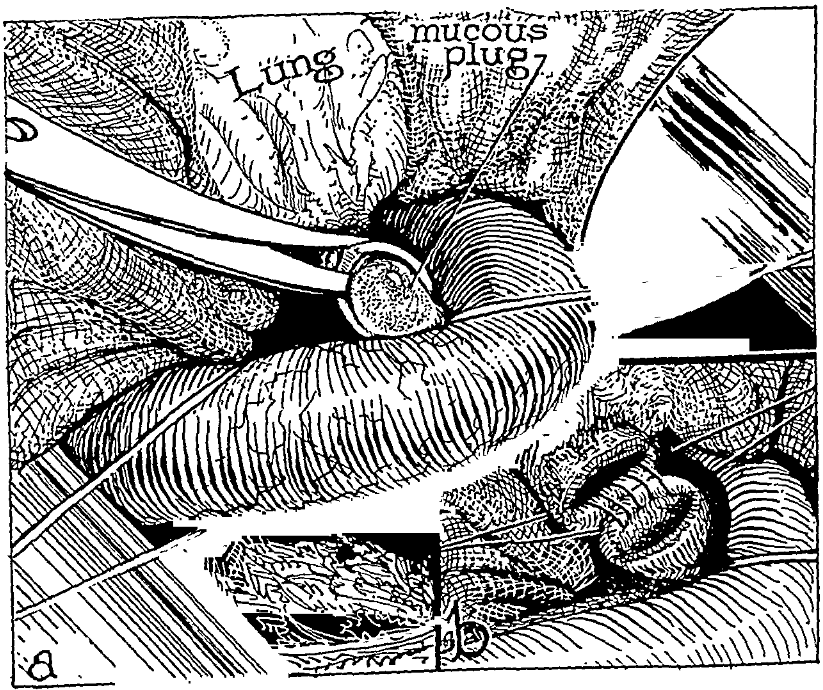

Fig. 5.—*A*, Drawing made at operation showing the gelatinous mucoid material exuding from the distal bronchial lumen after excision of the stricture. *B*, After resection of sufficient bronchial wall to provide a normal lumen, bronchial continuity is restored by end-to-end anastomosis. Simple, interrupted No. 3-0 black silk sutures are tied outside the lumen.

a severe, crushing injury of the chest with the force of injury being transmitted to a closed, hollow viscus.[4] Apparently a shearing type of force is brought to bear on the tracheal bifurcation with resultant rupture of one of the major bronchi.[23] The injury may be confined to the main-stem bronchus,[5, 9, 12, 14, 15, 18, 19, 21-23, 26, 27, 30-32, 34, 35, 38, 39, 43-46, 48] or may extend into the trachea, proximally,[1, 10, 17, 38, 45] or into the secondary bronchi, distally.[10, 11, 13, 23, 25, 37, 39, 42, 45] Hemoptysis, subcutaneous emphysema, and pneumothorax are common clinical manifestations. There may be variable degrees of shock with hypotension and tachycardia. Cyanosis may be a prominent feature. *In some instances, other associated injuries bring about the death of* the patient before symptoms of bronchial rupture are manifest. However, the majority of patients survive long enough for the diagnosis to be established and treatment instituted. The case reported here is very unusual inasmuch as hemoptysis, subcutaneous emphysema, and pneumothorax were not present. Apparently there was complete transection of the bronchus with interposition of the mediastinal tissues so that the rupture was completely sealed. In most of the cases reported, pneumothorax with a persistent, severe air leak is a prominent feature. If the leakage of air is severe enough, early thoracotomy may be required. On the other hand, conservative therapy may be adequate in the early treatment of the lesion and only in the subsequent postinjury period is the true nature of the condition apparent. If bronchial

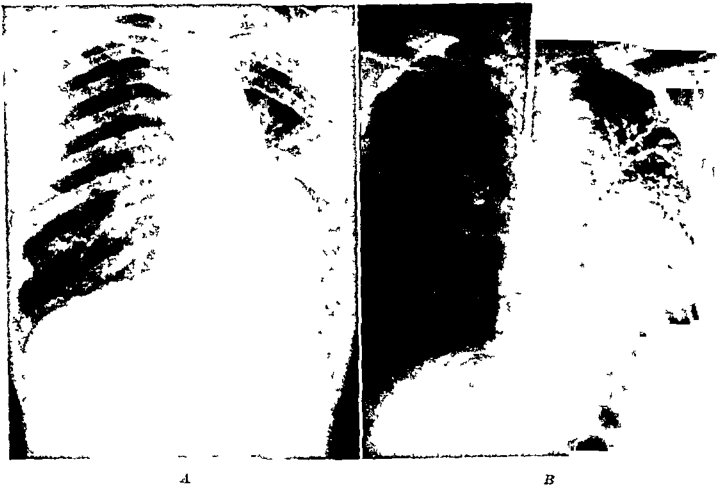

FIG 6.—*A*, Roentgenogram of the chest made approximately two months following operation showing re-expansion of the left lung, but with moderate elevation of the left hemidiaphragm The mediastinal structures are only slightly displaced to the left.

B, Bronchogram made seventeen days after operation shows a moderate amount of dilatation of the left bronchial tree There is minimal narrowing at the site of anastomosi

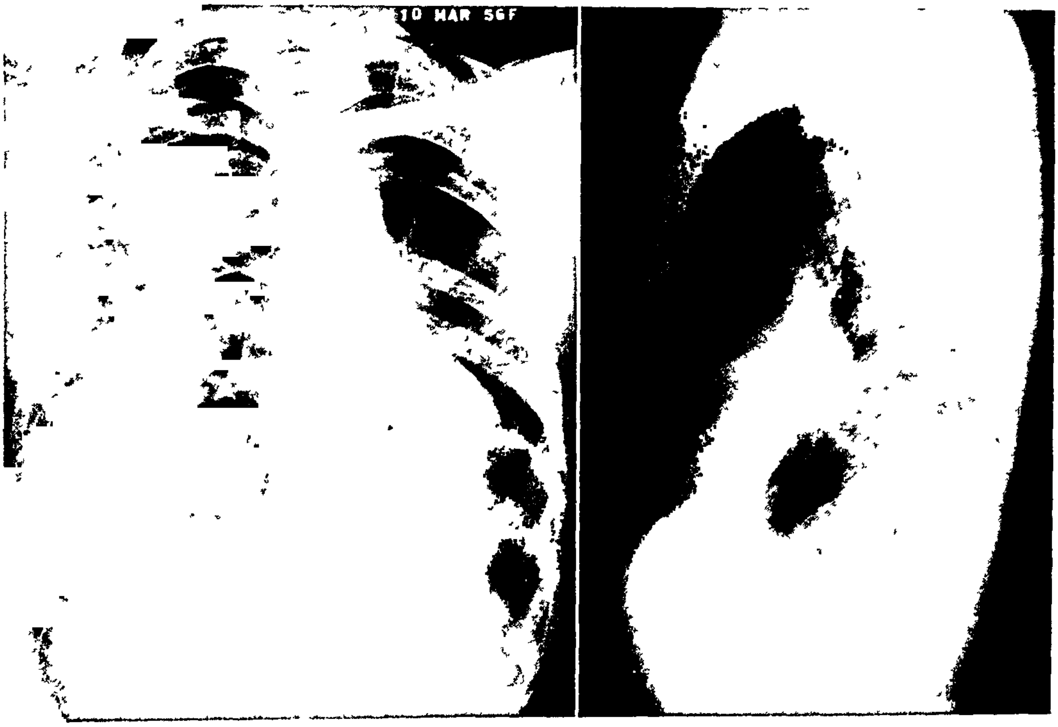

Fig. 7A.—Posteroanterior and lateral roentgenograms of the chest made five months after operation show increased expansion of the left lung.

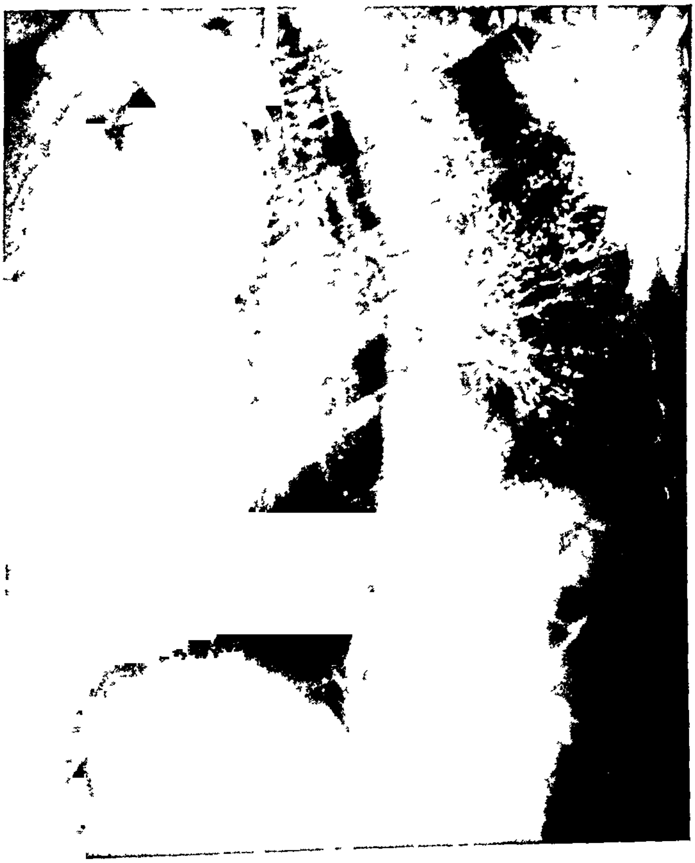

Fig. 7B—In a bronchogram made approximately six months after operation the previously noted dilatations are less apparent although crowding of the bronchial tree is still present. The site of anastomosis can be readily seen.

occlusion is incomplete, repeated infections in the pulmonary tissue distal to the injury almost invariably occur, manifested by pneumonitis or frank suppuration with resultant lung destruction requiring pneumonectomy.[23, 35, 39]

Several aspects of the operative management are worthy of emphasis. Although the prone position has been recommended for optimum exposure of the major bronchi,[3, 36] in this instance, the lateral decubitus position proved eminently satisfactory largely because of the marked mediastinal shift to the involved side. Partial mobilization of the distal aortic arch and the proximal portion of the descending aorta afforded better exposure of the tracheal bifurcation.[3] Following adequate exposure of the area of stenosis, the stricture was completely excised, sacrificing a minimum of normal bronchial wall in order to limit the degree of disproportion. The endotracheal tube was then guided into the right main-stem bronchus with a forceps passed through the proximal stump of the left main bronchus. Thus, positive pressure inflation of the contralateral lung was assured during bronchial repair. The viscid, gelatinous material which filled the bronchi distal to the stricture presented a problem inasmuch as it had to be completely removed before the lung could be re-expanded. It was suggested that one of the detergents be instilled into the bronchus in an attempt to liquefy this material, but aspiration through a small catheter proved successful so this suggested method was not employed. The anastomosis[3, 20, 21] was performed with interrupted simple sutures of black silk since this technique of closure has proved satisfactory for other types of bronchial repair. Tracheostomy was performed primarily as a precautionary measure although it undoubtedly obviated the need for bronchoscopic aspirations during the early postoperative period.

The apparent regression of the previously noted dilatations of the bronchial tree is of interest and adds objective evidence to the studies of Croxatto and Lanari[8] on the pathogenesis of bronchiectasis. They have postulated that complete bronchial obstruction is followed by atelectasis and subsequent "mucous bronchodilatation" secondary to continued secretion of the mucous glands and with the resultant dilatation being directly related to the increased intraluminal pressure rather than the effect of "external stretching." They further postulate that this phenomenon is apparently a reversible one if the factor of secondary infection is not introduced. Although they were unable to show this conclusively in the experimental animal, their hypothesis is nevertheless a valid one. The finding of a bronchial tree distended with mucus has been a constant feature in those cases operated upon several weeks to many years after injury, and histologic sections confirm the impression that inflammation and suppuration are not factors in the usual case of complete bronchial occlusion.[47] The changes noted in the bronchograms after an interval of six months show rather conclusively that this is a reversible phenomenon (Figs. 6 and 7).

Pulmonary Function.—As indicated previously, the mechanism for the production of bronchial rupture and the principles underlying its treatment are well established. On the other hand, little is known regarding the effects on pulmonary function of this injury and its subsequent correction. *In r* porting their experience with a patient operated upon forty-six days following injury, Weisel and Jake[48] described differential pulmonary function studies three months after operation. The injured side was found to have 37.3 per cent of the oxygen consumption, a tidal volume of 249 c.c., a vital capacity of 913 c.c., and a minute volume of 4,980 c.c. These compared with 62.7 per cent oxygen consumption, 300 c.c. tidal volume, 1,826 c.c. vital capacity, and a minute volume of 6,000 c.c. for the uninvolved lung. In a personal communication, the authors state that recent studies indicate an almost equal division of function between the two lungs.[49]

In an attempt to understand the altered physiology associated with this condition, available pulmonary function studies have been utilized. Serial postoperative studies are being done to evaluate the course of the patient from the functional standpoint in addition to the preoperative evaluation.

Methods.—With the patient in a sitting position, subdivisions of lung volume were measured by use of a 9.5 L. spirometer and expressed as volumes at BTPS. Minute ventilation, maximum breathing capacity (MBC), and timed vital capacity (TVC) were then measured. The studies were done preoperatively and at seven weeks and five months postoperatively. At the time of the last study the maximal midexpiratory flow (MMF) of Leuallen and Fowler[23] was obtained. Changes in lung volumes not susceptible to such measures were estimated by the roentgenographic method of Cobb and his associates.[6]

Although absence of bronchial communication to the left lung prevented preoperative bronchospirometry, the procedure has been done postoperatively within two days of the time of determination of total function. A Carlens catheter was used, with proper placement being judged by fluoroscopic position of the catheter, by the absence of transference, and by the change of tracing upon withdrawal. No difficulty was encountered with either catheter passage or placement. The influence of turning the patient from the supine to the right or to the left lateral decubitus position was observed. An unsuccessful attempt was made prior to operation to estimate the distribution of blood in the pulmonary vascular bed by the use of angiocardiography.

Arterial blood was obtained preoperatively and five months postoperatively. Oxygen content, oxygen capacity, oxygen saturation, and carbon dioxide content were measured by the Van Slyke manometric technique. These values are not entirely comparable as the patient was supine and sedated when the initial blood was obtained. At the time the patient was last studied, the response to exercise and inhalation of 100 per cent oxygen was determined. Exercise consisted of stepping up and down on a nine-inch step once every two seconds for three minutes.

The distribution of the inspired breath and volume of dead space was determined five months after operation by the single breath nitrogen washout test.[50]

Results.—The spirometric studies showed a striking lack of variation (Fig. 3). The change in vital capacity and MBC is within the error of the method. This observed invariance of vital capacity was seen although x-ray examination showed obvious redistribution of air within the chest, as did bronchospirometry. Integrated roentgenographic volumes were consistent with these findings. After operation, the right lung decreased in volume by 800 ml. which is of the same order of magnitude as the 600 to 900 ml. volume present in the left lung at bronchospirometry.

The vital capacity was below its predicted normal in spite of near normal values for TVC and MBC. The resting expiratory level was moderately elevated and has shown no change.

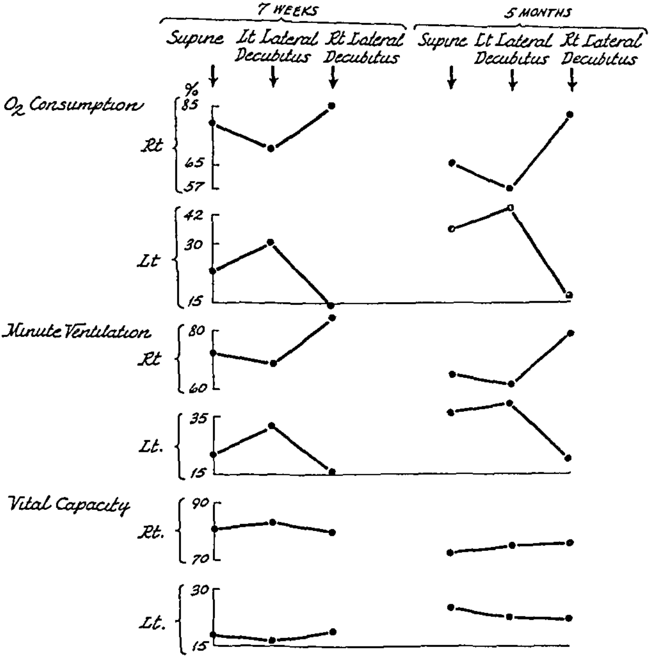

Fig. 8.—Data obtained at bronchospirometry seven weeks and five months after operation.

The addition of the maximal midexpiratory flow (MMF) at the time of last testing falls outside the normal range. This finding is at variance with the one-second TVC and MBC.

With the patient in the supine position, bronchospirometry, seven weeks following operation, showed an oxygen consumption in the left lung of 21 per cent, a minute ventilation of 28 per cent, and a vital capacity of 19 per cent (Fig. 8). Each of the values was slightly increased five months after operaporting their experience with a patient operated upon forty-six days following injury, Weisel and Jake[48] described differential pulmonary function studies three months after operation. The injured side was found to have 37.3 per cent of the oxygen consumption, a tidal volume of 249 c.c., a vital capacity of 913 c.c., and a minute volume of 4,980 c.c. These compared with 62.7 per cent oxygen consumption, 300 c.c. tidal volume, 1,826 c.c. vital capacity, and a minute volume of 6,000 c.c. for the uninvolved lung. In a personal communication, the authors state that recent studies indicate an almost equal division of function between the two lungs.[49]

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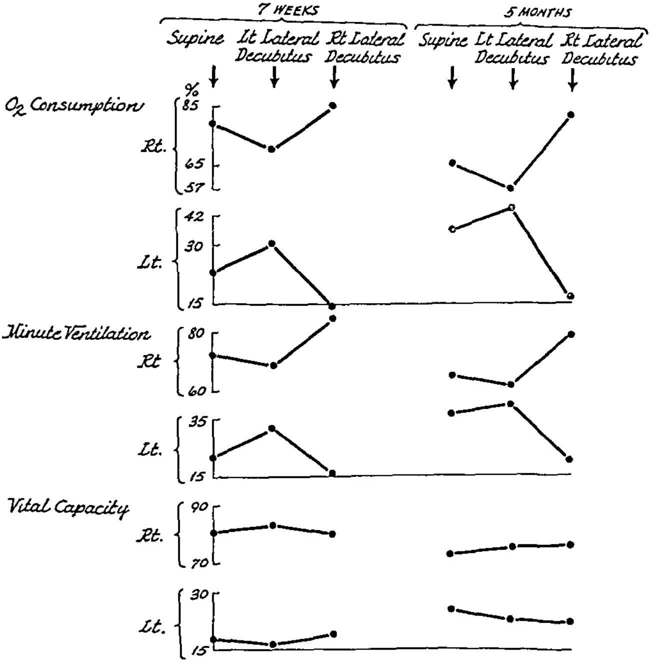

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The single breath nitrogen washout test showed a ''flat'' alveolar plateau. The per cent increase for 500 ml. of expired alveolar gas was less than 1.5 per cent nitrogen. Dead space as determined by the method of Wilson[50] was 100 c.c.

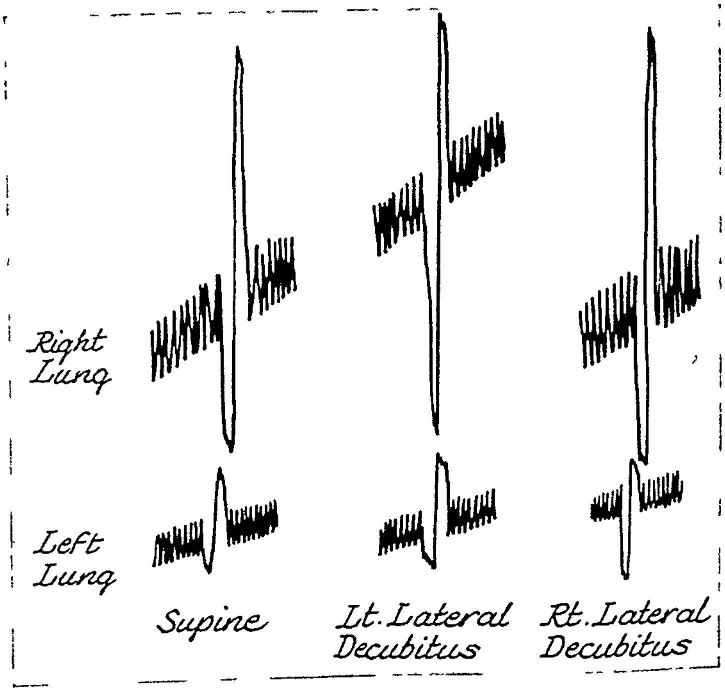
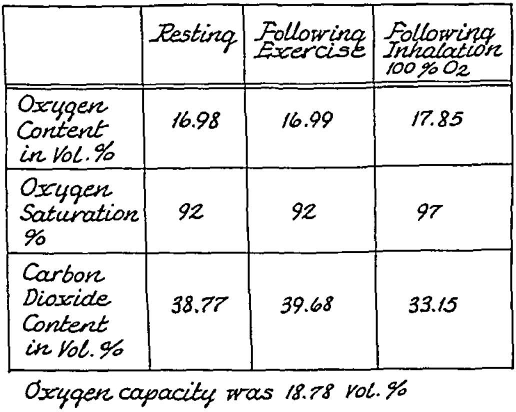


Fig. 9.—Bronchospirometry at five months showing the effect of body position on mid-capacity.

Preoperative blood gas studies at resting conditions showed an oxygen saturation of 94.5 per cent and PCO_2 of 47 mm. Hg. Five months after operation, blood gas studies revealed an O_2 saturation at rest and immediately after exercise of 92 per cent (Fig. 10). After three minutes of inhalation of 100 per cent O_2, the saturation rose to 97 per cent. The step test was performed easily and quickly, and at no time during exercise did the patient develop dyspnea or fatigue.

The most striking finding was the inability of the patient to reach complete saturation following inhalation of 100 per cent oxygen (Fig. 10). The method of Comroe[7] may be used to calculate the amount of shunted blood. As the patient had an oxygen capacity of 18.78 volumes per cent and 2 volumes per cent more oxygen would be present following inhalation of 100 per cent oxygen, the content of blood leaving the pulmonary capillaries was 20.78

volumes per cent. If it was assumed that the mixed venous blood had a content of 5 volumes per cent less oxygen than did arterial blood, then the ratio of shunted blood flow to total blood flow was 37 per cent. A difference of 1 volume per cent from this estimated value gave a range of shunted flow of 33 to 42 per cent.



	Resting	Following Exercise	Following Inhalation 100 % O2
Oxygen Content in Vol. %	16.98	16.99	17.85
Oxygen Saturation %	92	92	97
Carbon Dioxide Content in Vol. %	38.77	39.68	33.15

Oxygen capacity was 18.78 Vol. %

FIG. 10.—Blood gas values five months postoperatively.

Comment.—This case represents an extreme alteration of ventilation to blood flow relationship. Physiologically it is opposed to isolated pulmonary artery occlusion with its tendency to hypercapnia and increased dead space for, in the present case, direct measurement showed a normal dead space and an absence of hypercapnia. It demonstrates a low ventilation-perfusion ratio with the effect of a shunt and its tendency to cause anoxia. Failure to reach 100 per cent saturation after 100 per cent oxygen was inhaled is confirmatory evidence supporting the shuntlike effect. The absence of hypercapnia is against general hypoventilation as the cause of anoxia; the failure of saturation to fall with exercise is against a diffusional defect; and the normal single breath nitrogen washout test rules against uneven distribution of the inspired breath.

It was not possible to localize the shunt by available physiologic methods, thus the factors responsible for its development and persistence are not known. However, it appears that several abnormalities resulting from bronchial occlusion may have altered pulmonary circulation. As air volume on the left side decreased, negative intrathoracic pressure increased resulting in overdistention of the right lung. The net effect of this altered pressure relationship may have been to produce a shunt within the pulmonary vascular bed of one or both lungs. Mucus secreting glands, distal to the fracture site, continued to function so that air-containing spaces became fluid-filled spaces.[8] The magnitude of this pressure and its influence on circulation is unknown.

Another important factor may have been development on the left of a closed space filled with fluid which limited volume change to the gas-filled right lung. As exposure to inspired air was lost, the left lung developed a lower oxygen tension which has been shown to decrease blood flow acutely. However, its effect over a period of years is not clear. Finally, changes in bronchial artery circulation may have occurred, although inspection of these structures at the time of surgery revealed no abnormality.

When ventilation of the left lung was re-established, a shunt was present. It is possible that this shunt exists in the right lung, having developed during the long period of increased blood flow through that lung. However, it is more reasonable to assume it is on the left side, either because of localized thickening of the alveolocapillary membrane of sufficient degree to produce a shunt or because there is blood flow to areas as yet not ventilated.

An interesting observation is the shift of mid-position demonstrated at bronchospirometry. This probably represents a compliance change occasioned by change of vascular volume. Whether or not the vascular volumes are more labile than normal is not known.

The decrease of vital capacity would lead to a classification of the ventilation defect as a restrictive one. Curiously enough, the same ventilatory defect persists despite obvious redistribution of gas volumes within the chest cage, and points out the inadequacy of spirometry to give information about the distribution of the inspired breath.

The concepts defined by Otis and his associates[33] may be used to describe the mechanical changes in this case. The spirogram shows a high mid-position probably resulting from increased lung compliance. This change could result from an increase of compliance of one or both lungs. It could also result from a compliance increase on the right side which is greater than a decrease of compliance on the left. It should be remembered, however, that there is evidence for an increased "steady" compliance only, with the effective compliance unmeasured. Theoretically, the right lung which has been overdistended should be more compliant and the left lung, which has been in an extremely small volume for a prolonged period, less compliant. If this variation of compliance exists, a variation of *time constant* between the two lungs may be present resulting in a back-and-forth ("pendelluft") movement of air between the two lungs with uneven pressures applied to the circulation of each lung.

The abnormal MMF may represent a slight increase of resistance to airflow at the site of anastomosis. However, it seems more likely that the increase of compliance with its increase of airway resistance is more likely to be present under test conditions.

One of the most important questions remaining to be answered is whether the increase in oxygen consumption of the left lung, occurring during the first five months after operation, will continue until a normal level is reached. Observation of the patient over a long period of time, with determination of pulmonary function at intervals of six months, is planned in order to demonstrate further the pattern of recovery of lung function.

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DISCUSSION

DR. JAMES D. HARDY, Jackson, Miss.—We would like to present a similar case which we had about eight months ago.

(Slide) This was a 19 year old girl who was in a car wreck, sustaining fractures of the left femur, right radius, and both first ribs, plus head injuries. She had a left pneumothorax at the time of injury and a closed drainage tube was put in by the local physician; it was withdrawn three days later and although no expansion of the lung occurred she had no further respiratory symptoms. This shows the chest film taken at the time of admission to the University Hospital. Note the absence of aeration on the left side.

(Slide) We bronchoscoped the patient and found apparent occlusion of the left main stem bronchus approximately 3 cm. from the carina, and bronchogram confirmed this impression. I might say that, on the basis of the history and other findings, the possibility of complete traumatic separation of the left main stem bronchus was suggested by Dr. Watts R. Webb of our department.

(Slide) The left hemithorax was explored with the aid of a double lumen intratracheal tube. Note the pulmonary artery, the inferior vein, and in the center the distal end of the separated bronchus, with collapsed lung. We attacked the distal end first, snipped off the occluding scar tissue, got a good lumen, and then turned it down to the proximal bronchus which was just adjacent to and behind the aorta. We made no attempt, and no attempt was necessary, to mobilize the aorta.

We took a sterile tube and brought it over the anesthetist's shield and inflated the distal bronchus. The lung inflated readily after the relatively clear greenish mucus had been aspirated from the bronchus. We used No. 4-0 interrupted silk sutures tied inside the bronchus.

(Slide) This shows the patient approximately seven days following operation. Although there was fair expansion of the lung immediately following operation, this improved daily. Moreover, it required several days for the lung field to clear, presumably of retained secretions.

(Slide) This shows the patient ten days following operation.

DR. DONALD L. PAULSON, Dallas, Texas.—Dr. Mahaffey has demonstrated very well the feasibility of restoration of function in an atelectatic lung eleven years after healing of a traumatic rupture by complete occlusion. In our paper on the subject several years ago, we emphasized the fact that all the evidence, clinical and experimental, at that time indicated that these atelectatic lungs secondary to traumatic bronchial rupture, provided complete occlusion had occurred, could be re-expanded if bronchial continuity was restored.

(Slide) This illustrates a case six weeks after injury. The tear has healed by complete occlusion and continuity was restored by means of a dermal graft.

(Slide) This is a similar case six weeks later. Here, as in Dr. Mahaffey's case, pneumothorax was not evident at the time of the original injury. The ends of the severed bronchus were excised and an end to end anastomosis was performed.

The problem of acute bronchial rupture of course is divided into acute and chronic phases; the acute phase is far different from the chronic phase, the diagnosis must be made in many instances very quickly, early, if the patient is to survive.

(Slide) This illustrates such a patient with a tension pneumothorax and mediastinal emphysema and subcutaneous emphysema, with a large leak of air through the tubes in the pleural space, in spite of a tracheostomy. The illustration on the right is following repair of the bronchus.

(Slide) This is an illustration of the tear encountered at the time of operation. The diagnosis in these cases may be suspected on the basis of a tension pneumothorax with mediastinal emphysema, frequently in the absence of rib fractures, and may be well demonstrated bronchoscopically. One should be prepared for immediate thoracotomy in such a case, immediately following bronchoscopic examination. This bronchus was repaired at that time and the patient survived. It is doubtful that such a patient could go on to the chronic phase.

(Slide) This is simply another illustration of a torn bronchus involving the left lower lobe bronchus, as an acute problem.

DR. LYMAN A. BREWER, III, Los Angeles, Calif.—We have all enjoyed this excellent presentation of an extremely well-treated case. These conditions are being recorded with increasing frequency, yet no one's experience with them is very great today. In Los Angeles, we have treated 3 such cases; 2 were long standing, eight and ten years after injury, while the third was of short duration, six weeks after injury. Contrary to the experience of the authors, we were unable to re-expand the lungs on the affected sides in the two long-standing cases. This was due to fibrosis and cystic changes in the lung, which made the lung nonexpansile even though it was possible to restore the airway adequately. Subsequent pathologic examinations on these lungs were similar to chronic fibrosis, cystic change, bronchiectasis, such as one sees in chronic obstruction of the bronchus from other causes.

I think this poses an extremely interesting problem. Why did our long-standing cases show these chronic inflammatory changes and why, in the case reported today and some in the literature, was the pulmonary tissue relatively uninvolved? The basic factors are worth our consideration. We derived the impression that secondary infection in the lung probably was one of the most important basic reasons although one might consider extensive intrapulmonary hemorrhage, previous disease or impairment of the blood supply of the lung as other factors. But it seemed, in reviewing our cases, that infection was the primary factor. In the patient of six weeks' duration, pulmonary infection was controlled with antibiotics and we were able to repair the bronchus successfully and get an adequate expansion of the lung, while in our cases of long-standing complete traumatic rupture of the bronchus, no antibiotics had been used. Therefore, in the management of acute rupture of the bronchus if immediate surgery is not available, control of infection is probably one of the most important factors in addition to the other measures fundamental to the management of trauma.

DR. VICTOR H. KAUNITZ, Buffalo, N. Y.—Dr. Mahaffey and his group have shown a very excellent result in a well-studied case. I would like to present briefly a similar experience in which the outcome was not so fortunate, although the patient is fine now.

A 19-year-old girl, the driver of an automobile in a severe accident, sustained bilateral upper anterior rib fractures and bilateral pneumothorax. (Slide) This was treated within twenty-four hours by bilateral catheter drainage and both lungs re-expanded promptly.

(Slide) However, over the next few days there was progressive opacification of the left chest. The initial drainage from the left catheter had been bloody and we assumed we were dealing with a traumatic left hemothorax, but the patient ended up with complete opacification of the left chest.

The patient at this time was completely well, afebrile, and had been on continuous large doses of antibiotics. One month later she was transferred to our hospital in Buffalo from the rural hospital to which she had been admitted, for planned decortication. However, preliminary bronchoscopy showed complete obliteration of the left main bronchus at the level of the carina. We passed a small bougie through this, which I would not recommend, and then performed a bronchogram, passing a small catheter through this obliterated portion.

(Slide) Much to our surprise, the catheter was found to lie in the mediastinum and there was Lipiodol in the right pleural cavity. We also produced a very small right pneumothorax. The patient, however, had no difficulty from this and a few days later we went ahead with the planned left thoracotomy. After prolonged dissecting we were unable to visualize the proximal end of the left bronchus, nor could the anesthetist with gentle positive pressure expel any gas through it. There was considerable suppuration in the distal left main bronchus, and the only recourse was to perform a left pneumonectomy, which was done. The patient had an uneventful postoperative course and now, three years later, is quite well.

DR. THEODORE R. HUDSON, Chicago, Ill.—I would like to say that Dr. Mahaffey's recital is a tribute not only to the surgeon's skill but also to the staying power of the lung concerned.

(Slide) In spite of the fact that Dr. Mahaffey's patient and another one mentioned here today did not have a pneumothorax, I suggest that this problem of ruptured bronchus is primarily one of tension pneumothorax. The girl whose chest x-ray you seen in the slide was severely injured in a steering wheel accident and, as you see, has practically complete collapse of the right lung with severe subcutaneous emphysema. The needle you see in the lower part of the chest was put in by a surgical resident, in the wrong place obviously, but nevertheless I am convinced that it was lifesaving. This girl was operated on a few hours after the injury with a diagnosis of ruptured bronchus and at operation she was found to have the right primary bronchus completely avulsed from the trachea at the carina with loss of one complete ring of the primary bronchus. The bronchus was anastomosed to the trachea by simple suture as has been described in the cases discussed previously.

(Slide) This shows her condition now with a fully expanded and well-functioning lung. I would suggest that as a group we could afford to be a little more aggressive when it comes to dealing with tension pneumothorax, particularly following chest injury, and especially if subcutaneous or mediastinal emphysema can be demonstrated. In this way we will not only save lives but will be spared the much more difficult surgical problems similar to the one presented in Dr. Mahaffey's very excellent paper.

DR. RICHARD M. PETERS, Chapel Hill, N. C.—I will address my remarks to the problem of the shunt in these cases. We have done some work on atelectasis in this regard. There is a marked decrease in blood flow to the lung following atelectasis. This decrease in flow is not due, apparently, to the explanation which Dr. Liebow and his group have put forward namely, an hypertrophy of the bronchial arterial system causing back pressure and preventing a shunt, because if there is no infection in these lungs there is no hypertrophy of the bronchial arterial system. This has been shown in a number of dogs and I would like to suggest that this might answer Dr. Brewer's problem of how to determine whether one of these lungs is significantly damaged by infection. If there is an hypertrophy of the bronchial arterial system which is seen in bronchiectasis, tuberculosis, etc. it may be likely that there has been considerable damage from infection in the lung. If the bronchial arterial system, after dissecting the bronchus out, is normal, I think one can assume that there probably has been very little infection in the lung.

The shunts which you see here I am sure are in the range of flows seen during atelectasis in experimental animals and in human beings. It amounts to from 20 to 30 per cent of the cardiac output.

DR. DEWITT C. DAUGHTRY, Miami, Fla.—The patient, presented in our case last year, with fracture of the trachea and the right stem bronchus is continuing to do well, and I arise at this time to present a serious traumatic problem representing a little different type bronchial interruption. To my knowledge this is the second case of traumatic torsion of the lung to be presented and is the only one in which the patient survived surgery. The immediate and subsequent course was confusing but most interesting.

A 7-year-old girl was admitted to the hospital following a crushing injury to the left lower chest. She sustained a fracture of the left femur, several rib fractures on the left, and a ruptured spleen. A splenectomy was performed. The initial x-ray of the thorax showed some apparent congestion or early atelectatic changes in the left upper lobe. The x-ray changes in a few hours progressed to complete opacification of the left lung field associated with absence of breath sounds. There was no hemoptysis and no blood could be as-

such a case, immediately following [illegible] white blood count, and malaise
paired at that time and the patient [illegible] was operated upon with a preoperative
on to the chronic phase. [illegible] She was found to have a 180 degree
(Slide) This is simply an [illegible] with gangrene of all the lung except the
lower lobe bronchus, as an ac[illegible] at surgery that the viable superior segment in
[illegible] The other segments of the lung were

DR. LYMAN A. B[illegible]

cellent presentation of [illegible] vascular pattern in the left lung radiating upward and
corded with increasin[illegible] as you see on the opposite side. This is the diagnostic
In Los Angeles, [illegible] lead us to the diagnosis in its early reversible stage. The
after injury, whi[illegible] opacification of the left lung within a period of eight or ten
the experience [illegible] some thirty-six or thirty-eight days after injury, reveals break-
in the two h[illegible] parenchyma producing free air pockets or essentially multiple broncho-
which m[illegible] Multiple rib fractures over the left lower thorax are demonstrated.
quately [illegible]
fibro[illegible] color photograph taken at the time of surgery shows the one viable segment
bro[illegible] to the heart which is, of course, an abnormal location for this segment. The
[illegible] of the lung is gangrenous and one can visualize the loss of lung tissue in these
[illegible] representing abscess and bronchopleural fistulas. The next color photograph represents the necrotic segments of the lung which were excised. The color photograph shown here reveals the well-aerated superior segment of the lower lobe after reduction of the torsion and return of it to its normal location.

This composite slide of the immediate postinjury x-ray and the x-ray six weeks following surgery reveals a[illegible] more clearly the abnormal vascular pattern radiating superiorly and laterally, a[illegible] adequately the remaining superior segment has filled the left thorax.

the patient returned with a completely atelectatic right lung resulting from a stricture at the site of the bronchus repair Re exploration revealed the lesion to be such that reconstruction of the bronchus was not feasible

The fourth patient suffered injuries in a tractor accident, which crushed her chest and also caused fracture of the left clavicle We saw the patient six months after the injury and on physical examination and further investigation it became obvious that there was a transection of the left main stem bronchus The anatomic situation and the repair in this patient was very similar to the one shown by Dr Mahaffey The slides demonstrate the lesion prior to and after repair of the left main bronchus The bronchograms outline the area of reconstruction of the left main bronchus very well The patient at the present time is perfectly well with a normally functioning left lung

These types of injuries seem to be on the increase now, many of them are the result of crushing chest injuries suffered by drivers of automobiles—steering wheel injuries

DR PAUL C SAMSON, Lafayette, Calif —I have listened to this presentation with great interest and appreciate the essayist's reference to the case briefly reported before this Association two years ago by Byron Evans I believe it will be of interest to bring you up to date This patient is unique on three counts His successful bronchial anastomosis was performed fifteen years following the bronchial transection, which is the longest period known to us Second, the injury occurred at one year of age and the repair at age 16 This gave us an opportunity to observe an "infant" lung in an adolescent, since apparently there was little or no growth of the lung while it was functionless Third, this operation was performed nearly three years ago and it is, therefore, one of the early group of successful repairs for this type of injury

At present this young man has no objective symptoms of pulmonary dysfunction He engages in all types of athletics without difficulty There has been progressive improvement in timed vital capacity and in maximum breathing capacity as follows VC (1954), 1,925 c c , (1955) 2,300 c c , (1956) 3,650 c c MBC (1954), 72 L per minute, (1955) 90 L per minute, (1956) 134 L per minute X rays show the right lung to remain small, but there has been no relative change in the volumes of the right and left lung over the past three years The right diaphragm is still elevated and paradoxical The bronchograms show good segmental filling without atelectasis or bronchiectasis The ventilatory capacity of the right lung is over one half that of the left However, the oxygen consumption is less efficient and is only one fifth that of the left lung

I believe it is fair to assume that there must be some hyperplasia of the lung in response to the stimulus of use but, of course, there is no laboratory proof of this In any event, the patient has benefited greatly from his operation and there seems to be no question of the validity of the concepts that with complete traumatic transection, infection will *not* supervene, and that successful repair with a resultant usable lung may be performed many years after injury

DR OSCAR CREECH, JR, Houston, Texas (Closing) —We wish to thank the discussants for their remarks, and would like to emphasize that the two important features of this case are, one the fact that although the left lung was re expanded, there was no alteration in vital capacity, there was simply redistribution of inspired air Second, and more important, the failure of the patient to reach complete saturation of the arterial blood following breathing 100 per cent oxygen indicated a shunt of pulmonary blood flow of about 35 per cent This has shown a tendency to decrease with time and we feel that this test will provide the best criterion of recovery of lung function

CONGENITAL ATRESIA OF ESOPHAGUS

GEORGE H. HUMPHREYS, M.D., BRUCE M. HOGG, M.D. (BY INVITATION), AND
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NEW YORK, N. Y.

ALTHOUGH the pathologic anatomy of congenital atresia of the esophagus with tracheoesophageal fistula was known to pathologists as a rare and fatal curiosity for over two centuries,[1] clinicians did not become interested in making the diagnosis until thirty years ago, and development of effective treatment by surgeons occurred only in the last decade. The embryology, etiology, and incidence of the anomaly and its relationship to accidents of gestation and association with other anomalies are still uncertain. With a few notable exceptions, most of the increasingly numerous papers on the subject are concerned largely with reports of isolated cases, with various techniques of surgical management, or with series collected from such reports. It has seemed desirable, therefore, to collect and to summarize the record in a single center where a considerable experience has accumulated.

This report deals with 136 cases of congenital esophageal atresia with and without fistula seen at Babies Hospital or born in Sloane Hospital, both now units in the Columbia-Presbyterian Medical Center in New York, in the half century between 1903 and 1953. The majority of the patients have been seen, and most of these personally cared for by the authors, 27 having been previously reported.[2] The present series includes 101 patients who were operated upon, 32 of whom survived operation and 29 of whom were living and well at the time of this review.

EARLY DIAGNOSIS AND TREATMENT

The evolution of diagnosis and treatment in the group here reported is representative of the general experience with this anomaly. In the first 4 cases seen, in 2 of which attempts to pass a catheter into the stomach failed, attention was directed primarily to the esophageal atresia, though a note was made in one that "regurgitation of formula through the nose is suggestive of the presence of fistula." All were treated by gastrostomy only, and died of sepsis and pneumonia. Because of these discouraging results, the next 6 patients were not operated upon, and all died of pneumonia in the first week of life. This was the total experience in the first twenty years of the half century.

In 1923, diagnosis by x-ray was first carried out. The first x-ray was reported as demonstrating "congenital atelectasis." Following autopsy dem-

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onstration of the true nature of this unoperated infant's anomaly, a second case in the same year was diagnosed by contrast medium and an attempt was made to correct it surgically. In this procedure, Dr. Bolling not only performed a gastrostomy but also ligated the esophagus intraperitoneally. The ligature cut through and the infant died of peritonitis.

There followed a period in which x-ray diagnosis became increasingly accurate, but surgery was attempted only when no fistula was recognized. Of the next 12 patients, 9 were diagnosed during life and 3 were treated by gastrostomy, all dying of aspiration shortly thereafter.

In 1941, Dr. E. J. Donovan performed transpleural ligation of the lower esophageal segment and gastrostomy on 2 infants. In both, death followed cutting through of the ligatures. In the same year, Drs. W. G. Heeks and Hogg attempted a direct end-to-end anastomosis of the esophagus through a right retropleural approach, after dividing and ligating the fistula. Unfortunately, this operation, now the procedure of choice, failed through breakdown of the anastomosis, as did two subsequent ones performed the same year. One of these babies survived for two weeks, however, and gave encouragement to the concept that this condition might not necessarily be hopeless, although no survivor had yet been reported.

In the following year, 1942, an infant survived following division and closure of the fistula, cervical esophagostomy, and subsequent gastrostomy as described by Humphreys.[2] This procedure, essentially similar to successful operations previously performed by Leven[3] and Ladd,[4] was carried out *in 4 more cases the same year, with 3 survivors of the 5. The first patient* is now living and well, swallowing normally through a subsequently reconstructed esophagus, but the other 2 ultimately died of later complications.

In 1943, the first successful case of direct anastomosis in this series was performed shortly after a survivor of this procedure was reported by Haight and Towsley.[5] Since that time a direct anastomosis has been done whenever possible, cervical stoma and ligation being done only eight times in the seventy-nine operations performed in the next ten years.

Over the course of the early years of recognition of the anomaly and the attempts to correct it, it is interesting to note how cases tend to appear in groups. Recognition of one case apparently stimulated awareness of the condition, with the result that other cases were recognized within short periods of time, after which the characteristic symptoms appear to have been forgotten and cases perhaps missed for a time until another one was recognized. This phenomenon is apparent even in later years. In our own institution, cases occasionally are discovered at autopsy which were not recognized clinically. This emphasizes the importance of alertness to the possible presence of this defect and its characteristic symptoms in making the prompt diagnosis on which effective treatment depends.

CLINICAL DATA

The occurrence of this anomaly as seen at the Babies and Sloane Hospitals over this 50-year period is shown by 5-year periods in Table I. With

TABLE I. BABIES AND SLOANE HOSPITALS, TOTAL CASES—1903 THROUGH 1952

	NUMBER OF CASES
1903-07	1
1908-12	2
1913-17	4
1918-22	2
1923-27	8
1928-32	9
1933-37	7
1938-42	14
1943-47	37
1948-52	52
Total	136

recognition at the beginning of the last decade that successful operative treatment was possible,[2-5] there is a rapid increase in numbers seen. The conclusion seems inescapable that the defect is not as infrequent as the earlier experience implies, but that it either was unrecognized, or that little effort was made to treat it in the earlier period because of the apparent hopelessness of the situation. It is probable that the incidence has not changed, being about one in 3,000 births in the group from the Sloane Hospital included in this series, but in the past the anomaly was often overlooked and death ascribed to neonatal asphyxia, atelectasis, or aspiration pneumonia.

Increased awareness of the condition, as evidenced by an increasingly early age at the time of admission to the hospital is shown in Table II, which also shows an increasingly early age at which the diagnosis was made, especially in recent years. In general, delay in diagnosis and admission for treatment in the earlier group resulted in the children's being in less good condition due to dehydration and aspiration pneumonia, with correspondingly lower admission weights and higher mortality. The burden of early recognition falls largely on the obstetrician, the pediatrician, and the nursing personnel of the newborn nursery. If they are suspicious in regard to any child who has excess mucus, episodes of cyanosis, and who does not properly take fluid in the newborn period, more of these cases will be recognized earlier than at present, before a great deal of aspiration has occurred. There is no real

TABLE II. BABIES HOSPITAL CASES 1903-52
(STILLBORN, NEONATAL, AND AUTOPSY DIAGNOSED EXCLUDED)

	NUMBER OF CASES	AGE ADMITTED	AGE DIAGNOSED	NUMBER OPERATED UPON	NUMBER OF SURVIVORS	PER CENT OF SURVIVORS
1903-21	9	5.5	?	4	0	
1922-31	11	4.7	5.2	3	0	
1932-41	10	2.8	2.9	6	1	
1942-43	12	4.3	3.5	11	5	45
1944-45	14	4.0	4.1	13	1	8
1946-47	16	3.2	2.9	16	4	25
1948-49	19	2.7	2.5	18	7	39
1950-51	18	2.1	2.1	18	7	39
1952	12	2.0	2.0	12	8	66
Total	121	3.6	3.3	101	33	

substitute for awareness and careful, accurate observation. In many of the infants in this series, the nurses' notes had the diagnosis in them, whereas the medical histories did not.

Neither the clinical history, nor the physical findings have changed since the often quoted classical description given by Gibson[1] in 1703. Yet, in some of the old charts in this series before the defect was well known, many erroneous speculations were indulged in as to the nature of the anomaly. An important clinical observation is that the regurgitation or vomiting or coughing, as it might be more accurately described, of bile in these cases should not lead one astray and bring the question of intestinal obstruction too strongly to the fore. A number of these cases did reveal this type of history. In a few it was a reflection of intestinal obstruction at some other point in the gastrointestinal tract, but in most this was not so. One of the latter cases actually had been operated on at another hospital for intestinal obstruction prior to admission to Babies Hospital.

Although the diagnosis may frequently be made on history alone, physical signs and x-ray examination are usually necessary to confirm it. Almost all show signs of atelectasis or aspiration pneumonia, characteristically in the right upper lobe. Obstruction to the passage of a catheter through the esophagus, especially demonstration of its turning back upward into the pharynx on x-ray or fluoroscopy, may be sufficient and was often used in the earlier cases. Later, x-ray demonstration of the anomaly following a swallow of barium was frequently used. Although this delineates the lesion well, by 1941 it was realized that aspiration of barium into the lungs frequently resulted, and instillation of a few drops of radio-opaque oil with prompt aspiration after obtaining roentgenograms was substituted. This is useful in demonstrating the size and level of the upper pouch and often demonstrates also the presence and site of the fistula.

The presence of air in the gastrointestinal tract is clear-cut evidence of the presence of fistula between the tracheobronchial tree and the lower segment. Its absence, however, though suggestive, is not a sure sign of the absence of such a fistula. In one instance, lack of air in the stomach at two days, and in another at seven, led in the early period to this erroneous assumption. In each case, gastrostomy without closure of the fistula resulted in fatal aspiration of formula. Occasionally the lower esophageal segment may be demonstrated on lateral roentgenogram by the presence of air in it. Fistulas between the upper pouch and the trachea are usually impossible to demonstrate except by operative dissection.

EMBRYOLOGY

The type of anomaly in this series follows closely the experience of others, 122, or 90 per cent, being the 3b type of Vogt.[6] In this, the esophagus ends in a blind pouch high in the posterior mediastinum, and the lower segment originates in a fistula from the membranous portion of the trachea, the carina, or one of the primary bronchi. All but two of the recoveries fall in this group.

There were three instances of double fistula, in two of these the upper fistula was pharyngotracheal, entering the trachea just below the larynx. In another, there was an atresia with fistula and no lower esophagus. There was one stenosis of the esophagus with no fistula, and 8 cases of atresia with no

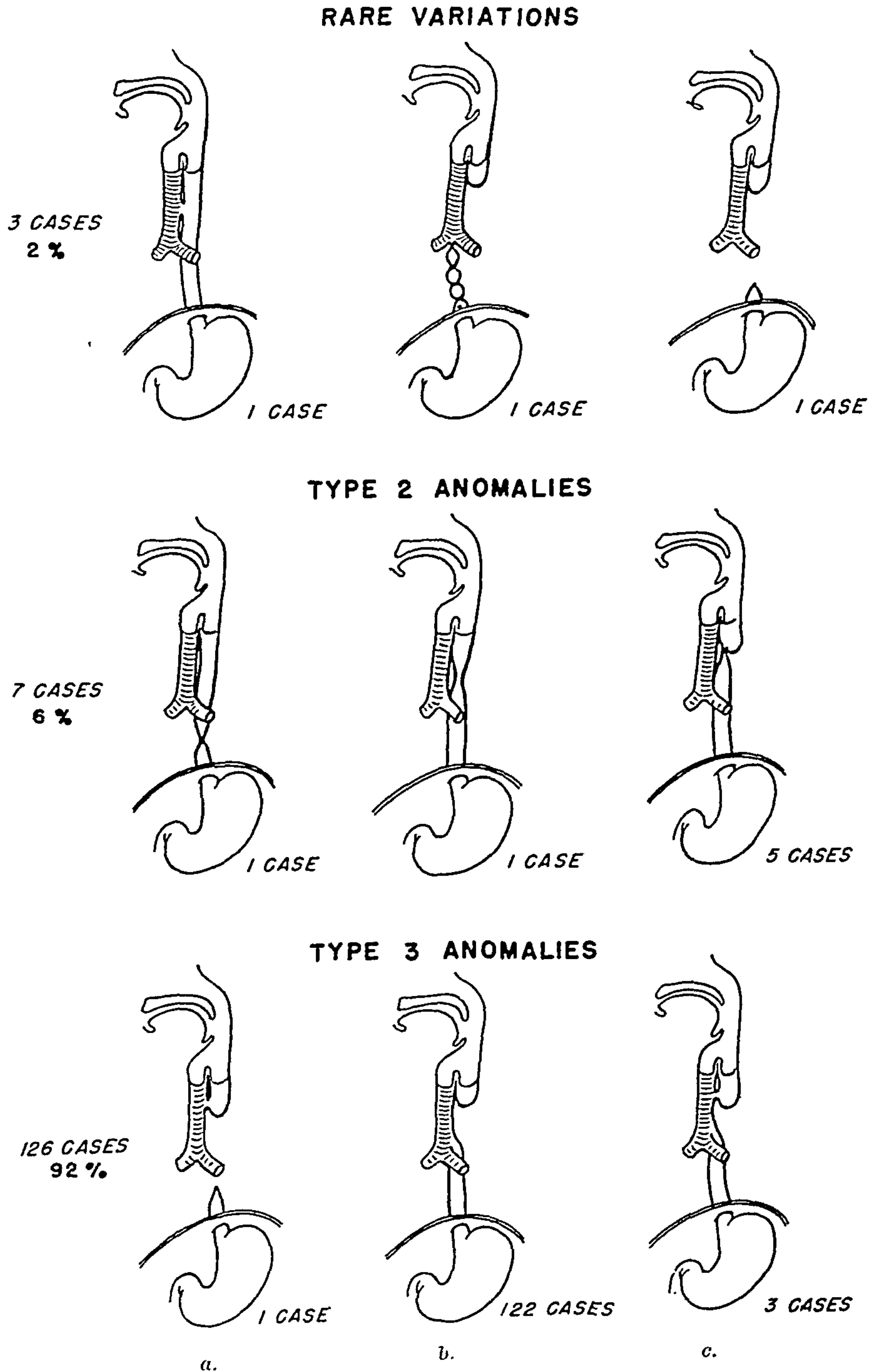

Fig. 1.—A diagram to show the types of anomaly encountered with figures illustrating numerical frequency of each. Ninety-two per cent were Type 3 anomalies; Type 3*b* in 90 per cent.

fistula, one with no lower esophageal segment, and the others with the lower segment present in varying lengths from one to several centimeters. In one of these cases, the lower esophagus consisted of multiple cysts joined by fibromuscular bands to one another and joining the trachea in the usual position just above the carina. In another case, the proximal point of atresia lay at the level of the eighth thoracic vertebra and extended distally for 1.5 cm. as a fibromuscular band, where the esophagus again became patent and normal in size. Finally, there was one case of fistula without stenosis (Fig. 1).

The etiology and the abnormal embryology of this defect have been the subject of considerable discussion. It seems probable that an incomplete cleavage between trachea and esophagus, together with the failure of recanalization of the esophagus, will explain all of the types of the anomaly. Complete transection without a discernible trace of connection to the trachea or lower esophagus has been seen occasionally in these cases, as is also seen in atresias of the small bowel, but the more usual finding is a persisting fibrous or fibromuscular band or multiple cysts making connection with the distal portion of the esophagus.

ASSOCIATED ANOMALIES

Of the total group of 136 patients, 75 are known to have had other congenital malformations. Among the 104 who died, 93 were examined at autopsy and 61 of these showed other anomalies; of the remaining 11 who were not autopsied, 5 showed gross associated anomalies. Thus, two-thirds of the infants who died were handicapped by other malformations. In contrast, among the 33 survivors only 9, or less than one-third, showed other anomalies and only one of these, a tetralogy of Fallot, was of sufficient severity to result fatally at an older age. The remainder are for the most part of minor nature such as hernia or hemivertebra.

FACTORS INFLUENCING SURVIVAL

Prematurity or low birth weight is a factor which adds to the risk of any surgery in the neonatal period. It is interesting to determine how these related factors have influenced the results in this series. Of the entire group 27 were listed as premature, 34 as full term, and in the remaining 75, the relation of the birth to expected term was not stated or not clear to the parents. The stated maturity, therefore, is of little help in relation to survival. More significant in relation to maturity is the birth weight. Of the entire group, birth weight was recorded in 125. The distribution among these in 500-gram groups is shown in Fig. 2, which also shows the corresponding weights among those which were born dead or died in the first day of life, in contrast to those who survived. As might be expected, deaths at or within twenty-four hours of birth were highest in the small and presumably premature babies, whereas the largest number (68 per cent) of survivors fall in the weight range from 2,500 to 3,000 grams. This is also the peak of birth weight range for the entire group and falls into the slightly premature or small full-term range. Although no child under 1,800 grams [illegible] it is interesting to note that three definitely premature infants of 1,800, 1,818 and 1,900 grams did survive operation and are now well. Thus, it appears that prematurity as judged by weight, though a determining factor at the lower extreme of size, does not preclude survival.

It is generally agreed that delay in making the diagnosis adds to mortality, largely because of the inevitable onset of aspiration pneumonia, especially if attempts are made to feed the baby. In the infants who survived more than one day but were not operated upon, the average age at death was 6.7 days, the longest survival being 18 days. Of the operated group, the average age at operation in the survivors was under 4 days, as contrasted with over 4 in those who did not survive. This is questionably a significant difference. In recent years, however, with earlier recognition, some delay has been deliberately introduced in preparing the baby for surgery so the groups are not strictly comparable. It remains our impression that mortality is less if the operation is done as soon as possible after birth.

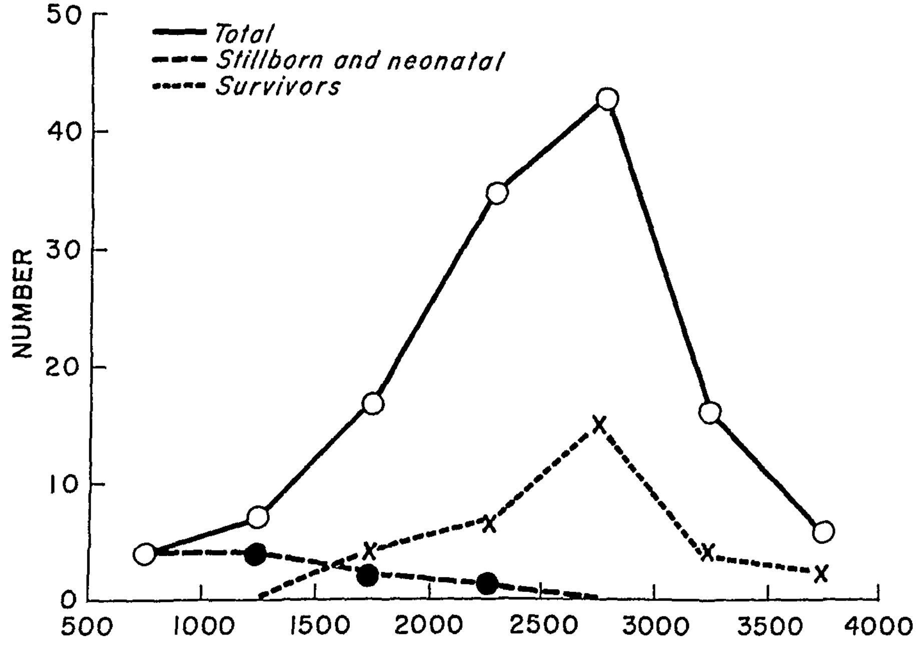

Fig. 2.—Birth weight distribution. Chart to show frequency by birth weight in 500-gram groups, of total group, the neonatal or stillborn group, and the group of survivors. The peak n total number and in survivor percentage falls in the 2,500- to 3,000-gram range. Below ,500 grams, there are no survivors and the majority die at birth or within twenty-four hours.

The preoperative care of these patients is important. On admission and after diagnostic procedures have been completed, the child is placed on nothing by mouth, put in an incubator with the temperature controlled and additional moist oxygen, and continuous nursing care is provided. The pharynx is suctioned every one-half hour with a small soft rubber catheter, the head of the incubator platform is slightly depressed, and blood to the amount of 15 to 20 c.c. per pound of body weight is made ready to go to the operating room. Infants who are jaundiced receive vitamin K preoperatively, and hydration is achieved by the use of a polyethylene intravenous catheter with a continuous drip of 5 per cent dextrose. Since these children are easily overhydrated, fluids in general do not exceed 75 c.c. per kilogram per day, of which only 75 c.c. or less is saline solution, the remainder being 5 per cent dextrose. It is no longer felt that operation should be done immediately as an emergency. Sufficient time, up to twenty-four hours, should be taken to restore hydration, give antibiotics, and restore pulmonary aeration by careful frequent aspiration. This will usually result in the infants' being better able to withstand operation than if operated on immediately after admission to the hospital.

The operative procedure has changed over the years. In the early group, gastrostomy only, with open drop ether, was uniformly fatal. Gastrostomy as a primary procedure is now reserved for the rare case at which there is reasonable certainty that a fistula does not exist. In the past ten years, this was carried out in 2 patients, one of whom survived and was found two years later to have a short segment of atresia. Successful resection of this segment and end-to-end anastomosis was then done. The other patient, who had no lower esophageal segment, succumbed to pneumonia thirty-two days after gastrostomy and thoracic exploration. The first survivals in the group here described were treated by retropleural divison and closure of the fistula and cervical esophagostomy under local anesthesia.[2] This method has the disadvantage of the need for feeding by gastrostomy for a long period and eventual reoperation to restore esophageal continuity. It is now reserved for the few cases in which the esophageal ends are so widely separated that they cannot be approximated without dangerous tension.

Since its first successful accomplishment in 1943, direct anastomosis has been the procedure of choice. If the infant is large enough, intratracheal anesthesia, usually cyclopropane, is used. Positive pressure with face mask only is preferable if the glottis does not readily admit a tube, and local anesthesia is still used in preference to inhalation anesthesia if the infant is very small or if there is much accompanying pneumonia. A right retropleural approach is preferred. Until 1946, a single layer anastomosis was done; since that time a two-layer technique as described by Haight has been used in most cases. In achieving a high percentage of anastomosis, even covering gaps of 2 or 3 cm., the following points are important. Dissection of the upper pouch high into the neck should be extensive, and painstaking, and complete separation of the pouch from the trachea, to which it is often densely adherent over a fairly long interval, should be accomplished. The fistula usually is approached first. It is separated from the trachea by a clean incision and the opening in the posterior wall of the trachea sutured with interrupted fine silk. This gives the anesthetist better conditions and obviates increased distention of the stomach. After the muscularis has been dissected from the mucosal portion of the upper pouch, the latter is brought down and sutured at appropriate points to the opening in the lower esophagus, which can be enlarged to an adequate size if necessary before opening the mucosal pouch of the upper segment. After it is once anchored, then the of the fistula, cervical esophagostomy and gastrostomy. Though the first patient to survive is now well at 14 years of age and swallowing normally, only one other of the 5 is similarly fortunate. The other 3 died, one at 3 months from aspiration pneumonia due to an unrecognized fistula between the trachea and upper segment, one at 2 years following acute gastric dilatation, and one at 3 years of tetralogy of Fallot. The third group of survivors are the 26 who were treated by retropleural anastomosis. This is obviously the most satisfactory method of dealing with the usual type 3b anomaly. With an over-all survival rate of 44 per cent, it is seen in Table II that this rate was improved to 66 per cent survivals in the last year reported. The most frequent cause of death in this group is respiratory failure in the first forty-eight hours after operation especially in small feeble babies, or those with other severe malformations. Breakdown of the anastomosis with secondary infection due to leakage, a common fatal complication in the earlier period, now occurs infrequently. When incomplete, recovery is possible but stricture often follows, requiring careful dilatation for periods up to a year or more. This complication may also follow anastomoses in which the lower segment is so small that formation of an adequate stoma is technically difficult. Such patients occasionally have difficulty due to lodging of solid food or foreign bodies in the esophagus, one of this series having been readmitted four times to remove pebbles, string, and food particles which caused obstruction. In no instance, however, has reoperation become necessary, and with growth a normal esophageal lumen and normal swallowing results.

SUMMARY

A brief history of the development of operative treatment for congenital anomalies of the esophagus at Columbia-Presbyterian Medical Center (Sloane and Babies Hospitals) in New York over the past one-half century is presented. This history parallels the experience in other centers and has resulted, beginning with the first survivor in 1942, in a salvage rate, in 1952, of 66 per cent. Factors influencing survival are seen to be the size and degree of prematurity of the infants; the association with other severe malformations; the awareness of doctors and nurses caring for newborn infants of the possibility of the condition and their alertness in recognizing the characteristic symptoms; the promptness with which patients are referred for surgery; the care in pre- and postoperative management; and the technical aspects of the operation itself. The first two factors are uncontrollable. The others leave room for improvement even in our own clinic. While occasional cases will present anomalies which require multiple-stage procedures before swallowing can be restored, in the majority of cases, successful end-to-end anastomosis of the esophagus is possible, with satisfactory restoration of normal swallowing.

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DISCUSSION

DR. ROBERT R. SHAW, Dallas, Texas.—This anomaly has been one that has occupied my interest from the time I started in practice in thoracic surgery. Like the experience of everyone else, at first it was a very dismal one, but later gave way to some optimism for expected recovery if a suitable infant was presented.

(Slide) This slide, which was prepared two years ago, shows our experience with this anomaly. Through the years up to 1948 there were only two survivals in 23 patients, but from 1949 on, the percentage of survivals became much better. During the years 1952-53, we had eight survivors out of 11 patients. The crux of success in the management of this anomaly is the anastomosis. We attempt to get an anastomosis in every patient and, in 56 cases of 61, an end-to-end anastomosis was accomplished. Admittedly, in many cases, the anastomosis was poor due to the fact that the segments were not of good length and there tended to be tension. Early leakage and late stricture formation are the complications resulting from poor anastomoses.

(Slide) This patient was interesting from the standpoint of multiple anomalies, in that the second anomaly other than the atresia of the esophagus, was obvious on the first film. This child had an atresia of the duodenum as shown by complete block at the second portion of the duodenum. However, this film was not available at the time of the first operation, since he was flown from a distant city to our city, and although five doctors came along, the x-rays were not brought with the patient. It soon became obvious that this second anomaly was present. It was also successfully repaired (by Dr. Warner Duckett of Dallas) on the twelfth day of life, and at the present time this child is a normal healthy boy of 6 years of age.

(Slide) This child is interesting because of the late period at which she was presented for surgery, and it illustrates the point that more reports of this sort should be in the pediatric literature. This child was 28 days old when she was brought to our clinic for repair of the atresia. The physician taking care of the child had advised the parents not to do anything about it even though the diagnosis had been made promptly after birth. He said if it were his own child he would do nothing about it. They had bought a burial plot and decided to let the child die. However, they did give the child a hypodermoclysis every day or so and kept it in some degree of hydration although it lost [illegible] of its six pounds birth weight in twenty-eight days. At the time of surgery an [illegible] very easy to repair was found and, because I felt that the anastomosis was adequate and the child's situation was somewhat precarious, I started the baby on mouth feeding the day following surgery. You can see by this slide that in eight days it was very [illegible] to demonstrate the point of anastomosis. We were never able to fill the baby [illegible] so hungry. Sometimes even with late arrival of these children it is possible [illegible] them.

DR. CAMERON HAIGHT, Ann Arbor, Mich.—The subject has been [illegible] thoroughly that I have very little to add but I particularly wish to comment [illegible] on the very excellent study which they have done. There are so many [illegible] in these infants that it is difficult to compare statistics and I shall [illegible] controllable factors which have been emphasized are of great importance [illegible] importantly to the results that can be obtained. We have been seeing a number of these infants with associated congenital heart disease and other anomalies, some of which in themselves are not compatible with life. We have come to the opinion that associated congenital heart disease should be treated by early operation if feasible for the reason that 4 of our earlier patients died as a result of their cardiac lesions. Although we have operated upon 4 patients with postoperative atresias for cardiac lesions, only one so far has been successful.

Another noncontrollable factor, at least to the surgeon, is the amount of pneumonitis which may have been precipitated by the preadmission use of contrast material and its entry into the lung. Although most of our infants have had Lipiodol contrast studies before admission, we believe that Urokon is a preferable roentgenologic agent if contrast material is to be used, but I have doubt as to the advisability of using any contrast material at all.

A controllable factor is the antibiotic coverage which is employed. For some years we have felt that the use of penicillin, streptomycin, and polymyxin B provided adequate antibiotic coverage; we find, however, that this is not enough and recently we have used a wide spectrum antibiotic in addition. With an all-inclusive type of antibiotic coverage, it is hoped that complications from controllable factors, such as pneumonitis and leakage of the anastomosis, can be avoided and that the recovery rate will thereby be improved.

DR. RALPH BERG, JR., Spokane, Wash.—I enjoyed this presentation very much also, and I have a patient that may be of interest.

(Slide) This child was operated on at about 18 hours of age. There was a proximal pouch end at this area. There was no fistula and no distal esophagus except for a small nubbin about 2 mm. above the diaphragm.

(Slide) This shows the repair accomplished by a transpleural approach with primary esophagogastrostomy.

(Slide) This is the child about one year postoperatively. The child is now three years postoperative and has had a stricture dilated five times.

Since this seemed unusual, after perusing the literature I present it at this time and would like to know if the authors had any similar patients in their series. I could not tell from the presentation.

DR. OSLER ABBOTT, Emory University, Ga.—I should also like to compliment this paper. I think certainly the name of Dr. Ladd should be mentioned whenever a discussion of this subject is brought up.

There are two things I should like to mention briefly. One is with regard to the use of Lipiodol, as mentioned by Dr. Haight. We have been interested in the bacterial content of the upper stump; it has a high content in some instances of anaerobic streptococci and we think the potential of the material in the upper stump has not been adequately emphasized. We recently had an episode of a fatal lipoid pneumonia due to overflow spillage of Lipiodol from the upper stump. Lipiodol was overzealously and overgenerously given in an x-ray department elsewhere. We have been struck recently with the importance of aspirating the upper stump with a catheter and then distending the upper stump with air, so that we get our contrast without soilage of the lung and without tendency to aspiration. We would like to mention the importance of the so-called H-type of fistula without atresia, which we have seen on three occasions, recognition of which can be very much delayed, and which does give a very happy result when found. One of our 3 had multiple associated anomalies; the other 2, one of which was recognized at 4 days of age, were successful.

Finally, I would like to mention that we are having trouble with reconstruction in the exteriorized patients who are now in their sixth, seventh, and eighth years, and we wish, in retrospect, that when we had brought the esophagus out into the neck, we had brought it out on the left side, which is the more normal anatomic deviation of the upper esophagus and does allow a better anastomosis to the stomach or other tissue brought up under the sternum

DR WILLIS J POTTS, Chicago, Ill —This fascinating subject is worthy of much discussion There is probably no operation which is packed with so many disappointments and heartaches as those on this particular group

During the past ten years we have operated on approximately 125 patients with tracheoesophageal fistula plus the usual atresia of the upper end It is our policy to operate on every child regardless of its condition—provided, of course, that it is still breathing, because there is no chance for the child without surgery During the first five years, our mortality varied from 40 to 70 per cent Then we made a number of radical changes Now the mortality has dropped considerably to 40 per cent in 1953, to 20 per cent in 1954, to 11 per cent in 1955 A few tough cases probably will alter our good fortune However, we believe that some of the things that account for this improvement are (1) intratracheal anesthesia, which we used to think was harmful for infants (2) transpleural approach, which is much faster, using the extrapleural approach remains so about one half the time, the rest of the time there is just a touch of the intrapleural, (3) an anastomosis, end to end, with two layers of No 6 0 silk suture, (4) in the post operative period the residents and nurses are constantly alerted to the dangers of aspiration and they all know how to aspirate these infants and keep the trachea clear, (5) the feeding of these children It took a long time to convince the nurses that they had to feed these children with a medicine dropper If, during the early postoperative period, one feeds these children with a nipple, the hungry child will eat too fast The upper end of the esophagus fills because of the usual minimal or moderate stricture at the site of anastomosis The child regurgitates and before anything can be done he has drowned in his own formula It is difficult to convince the nurses and one must be after them constantly With a medicine dropper they can give only one cubic centimeter at a time and the tragedy of drowning and aspirating formula into the lungs will be avoided

DR RICHARD KING, Atlanta, Ga —There is one complication I would like to mention, that is, the redevelopment of a fistula after the initial procedure

This occurred in a case of mine in September, 1955 The postoperative course was uneventful for approximately three weeks The baby at this time began to have respiratory difficulty at the time of feedings, with paroxysms of coughing and cyanosis An esophagram was done and a fistula was demonstrated between the esophagus and trachea at the site of the closure of the trachea and the anastomosis of the esophagus A right transpleural thoracotomy was done again, and the fistula between the trachea and the esophagus was located and taken down The openings in the trachea and the esophagus were then closed with interrupted silk sutures To prevent redevelopment of the fistula, a pleural graft was sutured between the esophagus and the trachea I feel that the use of a pleural graft is a very important part of the procedure and that it should be used in all cases at the initial procedure

Drs Shaw and Paulson in their excellent article on the subject last year mentioned the use of mediastinal fascia between the trachea and esophagus to prevent development of a fistula

DR GEORGE H HUMPHREYS, New York N Y (Closing) —I wish to thank all the discussants We could go on discussing this subject for a long time because there are so many bad results and so many different ways of getting them At the outset, I should like to assure you that the paper gives due emphasis to the pioneers in this field One thing that interested us was the fact that there were people working in various centers on the same subject at about the same time I believe Dr Lanman had worked with Dr Ladd on these babies for a number of years at Children's Hospital in Boston, and that Dr Ladd was disappointed to find that his first survivor was operated on just one day after Dr. Logan Leven's survivor, because neither knew of the work of the other. Our first survivor was operated on several months later by a similar technique. We also did not know at that time of the successful cases of either Dr. Leven or Dr. Ladd.

Dr. Shaw and Dr. Haight both were pioneers in the field, and to Dr. Haight goes the credit of demonstrating that direct anastomosis is the obvious and best procedure. We had given it up after several failures, apparently prematurely, because we now know how to do it as Dr. Haight has shown us. The obstruction that Dr. Shaw showed is very interesting. We also had 2 cases of obstruction, one at the duodenum similar to his, and one hypertrophic pyloric stenosis. These must be watched for, especially if feedings do not go well.

The antibiotic coverage which Dr. Haight emphasized is extremely important, and certainly the difficulties with the bacteriology and the contrast medium in the stump as described by Dr. Abbott are a common experience with all of us, and must be looked for. I think contrast material is a mistake. It is not necessary, the stump can be demonstrated, the lesion can be demonstrated by a double catheter or, as he suggests, by air, and it is far better not to use any contrast medium. Unfortunately, however, we usually get the patients with contrast medium already in them.

Dr. Potts has brought out the factors which implement survival, and his survival rate certainly depends on all of them. I would emphasize particularly, as he did, the postoperative care both in feeding and in aspirating these patients. Both the house staff and the nursing staff should be specially instructed, there should be special people who know how to handle these babies, otherwise the mortality is bound to be higher. I take issue with him only on the intrapleural approach, but this is a small factor and probably not important.

We did not encounter recurrence of a fistula. I think perhaps the method of closure of the membranous portion of the trachea is a large factor in this. We were lucky in the first few cases in which we ligated, and now we close it very carefully with interrupted fine silk and have had no difficulty on that score.

TOREK ESOPHAGECTOMY

THE CASE AGAINST SEGMENTAL RESECTION FOR ESOPHAGEAL CANCER

WILLIAM L WATSON, M D , JOHN T GOODNER, M D (BY INVITATION),
THEODORE P MILLER, M D (BY INVITATION), AND GEORGE T
PACK, M D (BY INVITATION)
NEW YORK, N Y

AN INTIMATE knowledge of the anatomy of the esophagus is helpful in understanding the peculiar dangers and difficulties encountered in the treatment of cancer of this organ One recalls that the esophagus is a thin walled flexible muscular and mucosal tube about 25 cm in length The esophagus differs from the other portions of the intestinal tract in that it lacks an outer, serosal covering and this is a distinct surgical disadvantage[5] The esophagus has a scanty blood supply, but a rich network of lymphatic vessels in its submucosal and muscular coats which provide a ready submucous pathway for the lymphatic dissemination of cancer

From the surgical point of view, it is obvious that the thoracic esophagus is deeply situated and intimately surrounded by important and vital structures which are often invaded early in the natural course of esophageal cancer The esophagus is insensible to pain stimuli and when backache, substernal discomfort or pain do exist it is almost certain that disease has extended through the esophageal wall into the mediastinal structures Since pain is a late symptom, it follows that cancer of the esophagus when first diagnosed is apt to be an advanced disease

From the anatomic viewpoint, the esophagus provides a fertile field for the silent development and spread of intrinsic cancer and at the same time it poses serious and sometimes insurmountable obstacles in adequate surgical management

LYMPHATIC SPREAD OF ESOPHAGEAL CANCER

Cancer of the cervical portion of the esophagus spreads early and with great regularity to the anterior, superior mediastinal as well as the lower deep jugular and prescalene lymph nodes If the malignant growth is located in the lower third of the esophagus, the dissemination is usually by way of the extrinsic lymphatics to the periesophageal and perigastric lymph nodes Mucosal and submucosal extension downward into the cardia of the stomach often causes some question as to whether the primary cancer arose in the esophagus or in the stomach

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Read at the Thirty sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach Fla May 7 to 9 1956

The upper third of the thoracic esophagus is apt to develop large, ulcerating, badly infected cancers which metastasize readily by way of the rich submucosal lymph vessels into the adjacent mediastinal lymph nodes (Fig. 1). It is important to note that these same intramural lymphatic vessels also distribute the neoplastic cells in a longitudinal direction often to a considerable distance above or below the visible or palpable limits of the primary cancer.

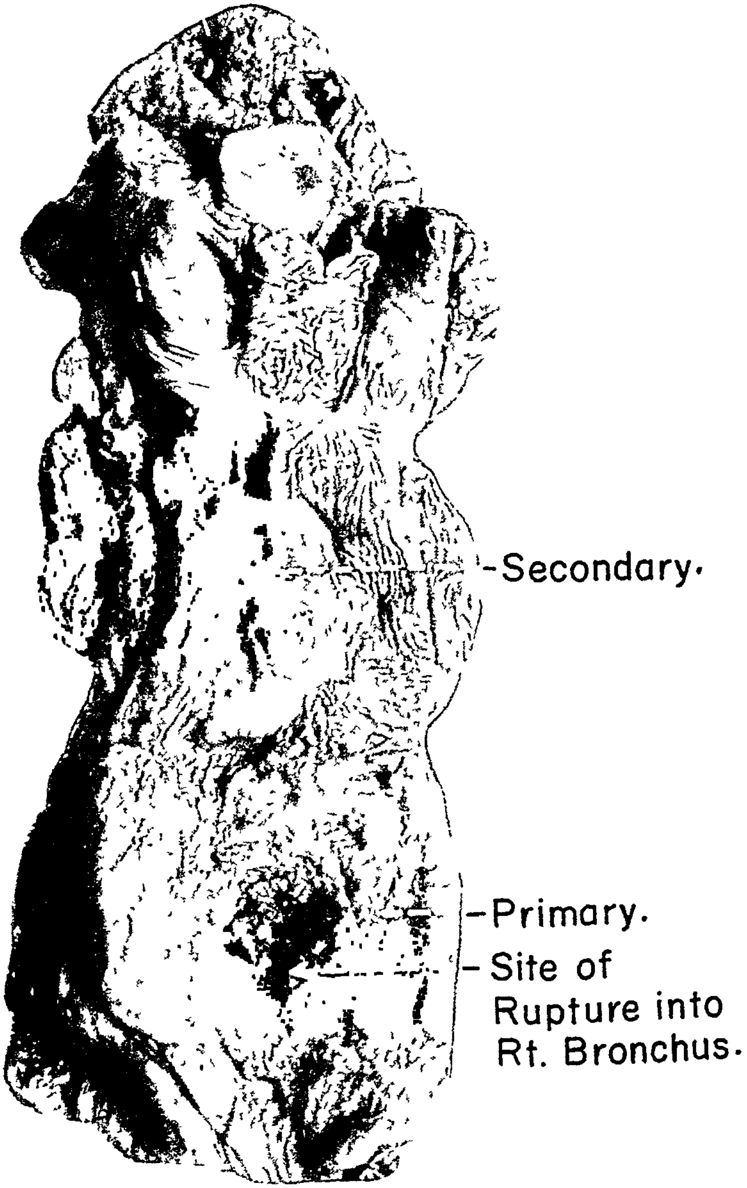

Fig 1.—The gross specimen shows a large primary carcinoma of the esophagus perforating into the right bronchus causing death by asphyxia A large secondary growth 5 cm in diameter is seen several centimeters above the primary lesion Microscopic section showed the lesion to be an epidermoid carcinoma, grade III.

Viable tumor emboli may block a lymphatic branch and give rise to a secondary deposit which presents as a submucosal outcropping (often under an intact mucosa) sometimes as much as 8 cm distant from the primary cancer

The above data were first noted during the study of a number of gross specimens of esophagus cancer by serial microscopic examinations Prior to this work of 1933, it was not uncommon to encounter, in the literature, case reports of multiple esophageal cancer It is now our opinion that in most instances these were examples of submucosal cancer metastases Simultaneous, multiple esophageal cancers probably are most uncommon

Doctors, in general, agree that an adequate surgical operation for cancer requires a wide resection of the primary growth in continuity with the regional lymphatic vessels and lymph nodes In the case of cancer of the esophagus, the surgeon's attention has been focused on the lateral spread of disease and its extension into structures and little attention has been paid to the longitudinal dissemination of the disease Perhaps as a result of the known poor prognosis for malignant lesions of the upper two thirds of the esophagus, surgeons have come to regard resections in this area as primarily palliative procedures requiring only a local resection of the tumor with immediate reconstruction

An early review of our cases of esophageal resection indicated a higher incidence of inadequate longitudinal excision than we had anticipated[3] Seventy nine cases were analyzed and 45 per cent of the patients with esophageal cancer who were subjected to segmental resection had an inadequate longitudinal removal of their disease Surgical failure was established in the following criteria (1) Microscopic evidence of cancer at the margins of the resected surgical specimen, (2) subsequent microscopic evidence of recurrent tumor by biopsy obtained at the line of anastomosis, or (3) miscroscopic proof of tumor at the line of anastomosis in the autopsy specimen Pathologists are prone to take longitudinal specimens at the line of esophageal transection for immediate frozen section diagnosis at the time of operation and it seems clear that transverse sections are required if one is to discover submucosal lymphatic cancer at the site of resection

In order to cut down the local recurrence rate and possibly increase the cure rate it was obvious that a longer portion of the esophagus needed to be removed and it was decided to do a series of Torek esophagectomies Forty eight patients had this type of excisional surgery The original Torek esophagectomy, successfully performed in 1913, left the patient with a messy anterior chest wall esophagostoma and a troublesome gastrostomy feeding problem Both these features of the operation are undesirable

The esophagectomy we favor is similar to that of the Torek operation only in that it is done for cancer and, as far as possible, all the esophagus with its lymphatics is removed The operation differs from Torek's procedure in that our approach is through the right chest and an immediate or staged esophagoplasty is carried out Only 31 of our 48 patients who had total esophagectomy for cancer of the upper two thirds of the thoracic esophagus were suitable for esophagoplasty

Six different methods of esophagoplasty have been given a trial. The first attempts employed rubber and plastic tube contrivances. After trying a few of these, the results were unsatisfactory and they were given up as hopeless (Figs. 2 *A* and *B*). Next we tried cutaneous, anterothoracic esophagoplasty in 6 cases and ran into the usual complications of gastric regurgitation, ulceration, stenosis, and prolonged morbidity (Fig. 3). In 2 cases an anterothoracic jejuno-esophagostomy (Fig. 4) was carried out and in 4 cases a retrosternal jejuno-esophagostomy was done. One of these patients is alive and free of disease more than five years after surgery. We also had some success with gastroesophageal anastomosis in the neck; this type of esophagoplasty was carried out in 10 cases.

In the last seven attempts at total esophagoplasty, we have employed retrosternal right colon transplants. In reporting this small group, it must be kept in mind that each patient had cancer located in the upper two thirds of his esophagus and in each instance the lesion was resected through a right thoracotomy incision by a procedure which in some respects is similar to the one devised and successfully carried out by Dr. Franz Torek in 1913. The use of right colon for total esophagoplasty is not a new idea. It was first reported in 1911 by Kelling[1] and, in 1934, Ochsner[2] collected 20 case reports from the literature. The majority of these were from European clinics and the surgeons brought the colon up to the neck through a subcutaneous tunnel. Dr. Charles D. Sherman[4] has called attention to the value of this type of esophagoplasty and has recommended the use of a retrosternal tunnel for the transplanted colon.

The procedure which we follow for cancer of the upper two thirds of the esophagus consists of two stages. First, a Torek type total esophagectomy through a right posterolateral thoracotomy and at a second stage, two weeks later, a right colon substernal esophagoplasty.

INTRATHORACIC RIGHT COLON ESOPHAGOPLASTY

In addition to the usual large bowel preparation for surgery, it is advisable to have a routine barium enema to determine the approximate length of the right colon and rule out any pathologic condition of that portion of the bowel.

(Fig. 5) At operation, after mobilization of the right colon, the right colic artery is temporarily occluded for fifteen minutes during which time the appendix is removed and the stump inverted (Fig. 6). If the blood supply to the cecum is adequate and arterial pulsations are visible then the occluded blood supply is divided. The transverse colon is divided just to the left of the mid-line. The terminal ileum is then divided and its distal end turned in after which bowel continuity is re-established by end-to-end ileotransverse colostomy.

(Fig. 7) A retrosternal tunnel is developed and the colon is brought through it taking care not to twist, kink, or otherwise compromise its blood supply. The cecum is anastomosed to the distal cervical esophagus and the final step is the anastomosis of the lower end of the colon transplant into the

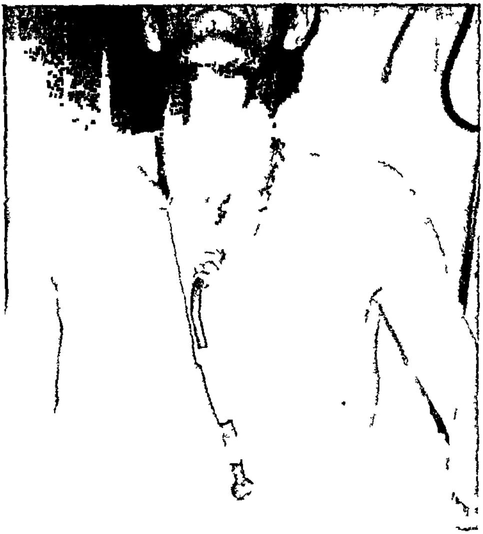

Fig 2 —A Front view Torek esophagectomy performed July 16 1941 for cancer Temporary rubber and glass apparatus permits the patient to take fluids and swallow his saliva

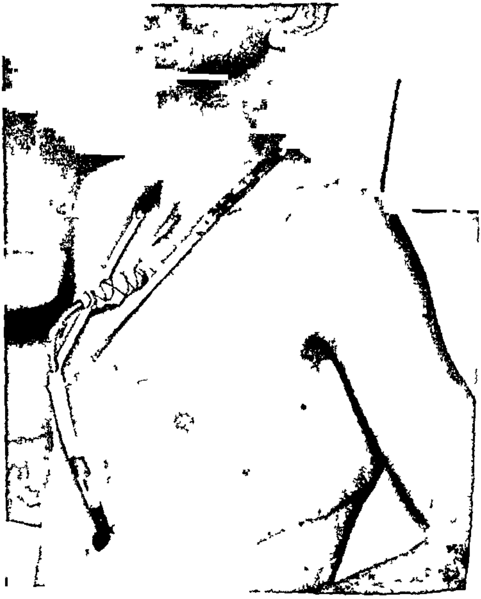

Fig 2 —B, Oblique view Torek esophagectomy performed July 16 1941 for cancer Temporary rubber and glass apparatus permits the patient to take and swallow his

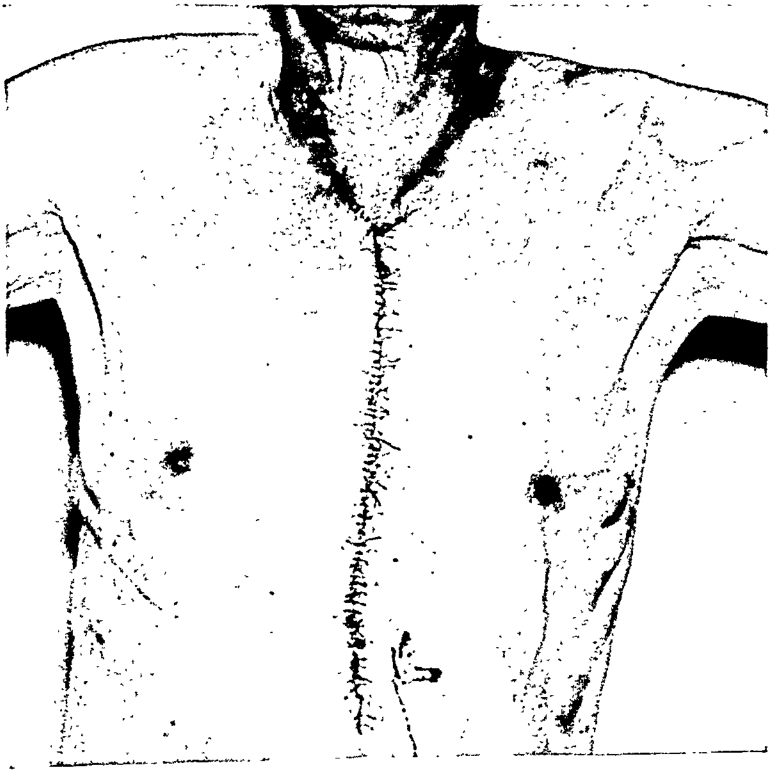

Fig. 3.—Torek esophagectomy performed April 8, 1954. The gross specimen revealed a submucosal metastasis 6 cm. above the primary growth. A cutaneous anterothoracic reconstruction was made on May 6, 1954.

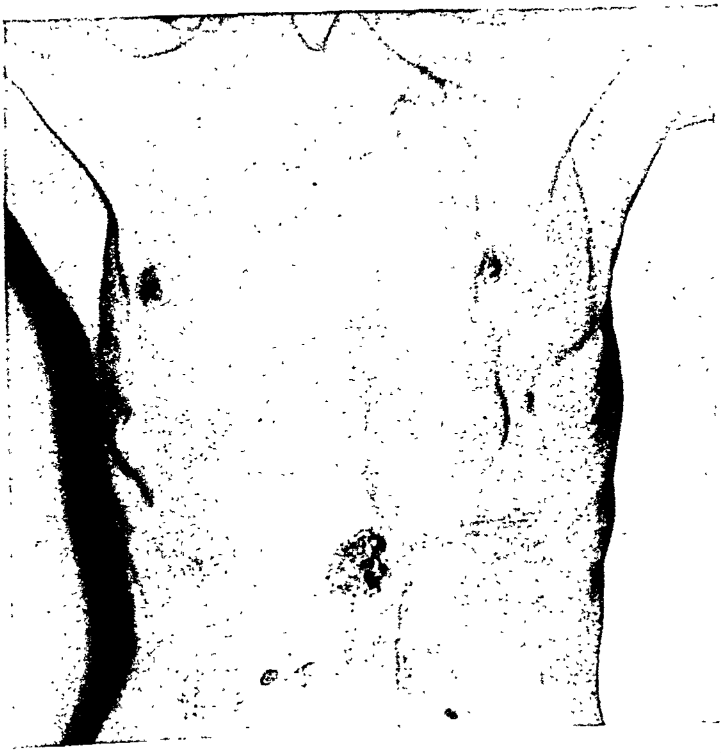

Fig. 4.—Torek esophagectomy performed on Oct. 3, 1949, for cancer. Anterior thoracic jejuno-esophagostomy, May 18, 1950. Patient is alive and well six years later.

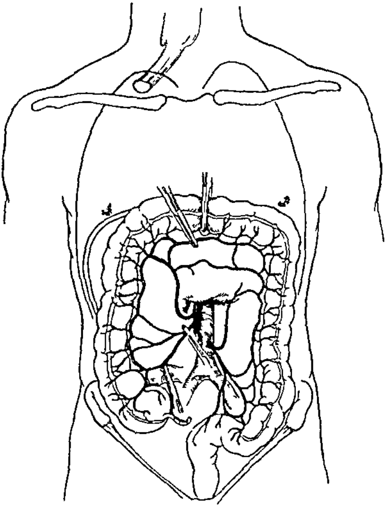

Fig 5 —The right colon has been mobilized and arterial clamps applied to the right colic artery and all other blood supply except that through the middle colic artery

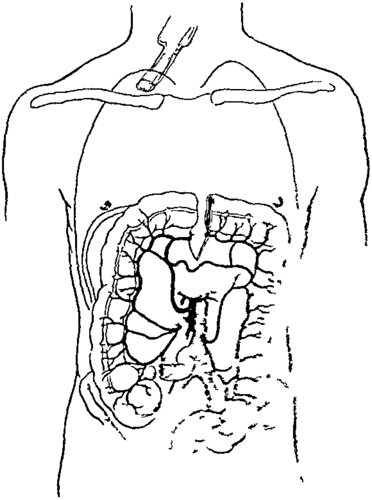

Fig 6 —The transverse colon is [illegible]
is [illegible]

anterior wall of the stomach. After the wounds are closed a chest roentgenogram is taken in order to detect any evidence of pneumothorax which would require correction.

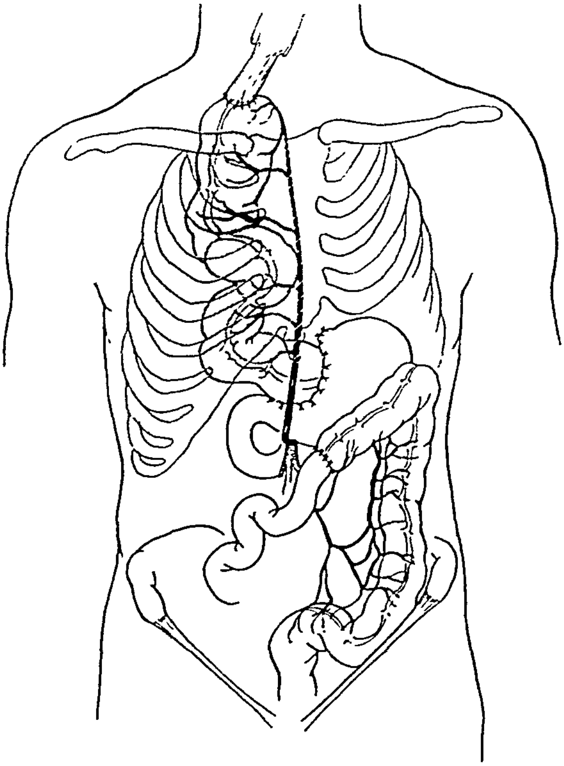

Fig. 7.—Bowel continuity is re-established by end-to-end ileotransverse colostomy. The right colon segment is brought up through a substernal tunnel into the neck where it is joined to the cervical esophagus. The lower end of the colon transplant is anastomosed to the anterior wall of the stomach.

CASE REPORT

F. A., a 56-year-old white man, pharmacist, whose present illness began three months prior to hospital admission with slight "heart burn" followed soon afterward by dysphagia. During the following two months, the dysphagia gradually increased in severity until solid food could not be taken and even liquid food caused considerable difficulty and some discomfort.

On the first visit, his physician made radiographic studies and a clinical diagnosis was established and the patient advised to come to the United States for surgical treatment. During the present illness, the patient lost about 10 pounds.

X-ray studies (Fig. 8), including fluoroscopic examination of the esophagus, and esophagrams were reported as showing carcinoma of the mid-portion of the esophagus, measuring 3 cm. in length and showing partial obstruction to the barium flow. Chest films were normal.

Esophagoscopy and bronchoscopy were carried out July 18, 1955, and a biopsy from the esophagus, at 33.5 cm. from the upper incisor teeth, was reported as showing epidermoid carcinoma. A normal tracheobronchial tree was encountered on bronchoscopy. The medical and laboratory evaluations of this patient for surgery were reported as good.

On July 22, 1955, a Torek type of esophagectomy was carried out without incident through a right posterolateral thoracotomy incision. The patient made a most satisfactory postoperative adjustment and was fed adequately by gastrostomy tube (Fig. 9).

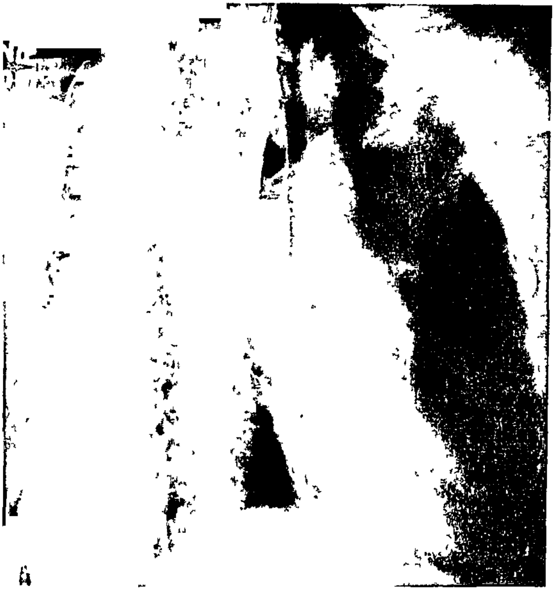

Fig 8 —Esophagram made July 15, 1955, showing cancer in the middle third of the thoracic esophagus.

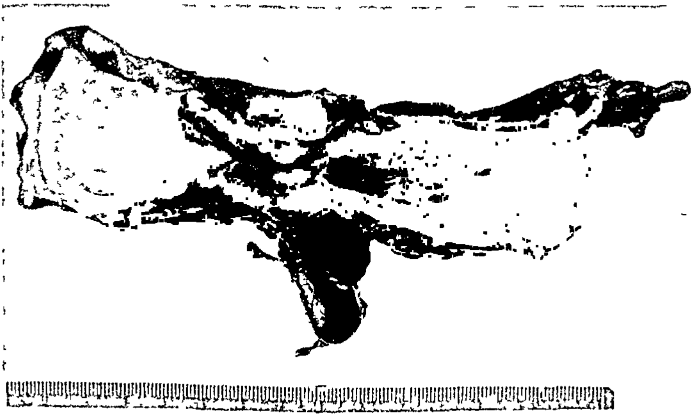

Fig 9 —The surgical gross specimen consists of a 16 cm segment of esophagus Attached to the middle of the specimen were two soft gray-pigmented lymph nodes The largest was 3 cm in its greatest diameter These were microscopically negative for tumor. The opened esophagus revealed an ulcerated tumor mass located in the middle third of the specimen and measured 2.5 cm in its longitudinal axis The upper margin of the tumor was 6.5 cm from the margin of excision and the lower margin of tumor was 7 cm. from the lower margin of excision The histologic diagnosis was epidermoid carcinoma of esophagus, grade II Attached nodes were negative

region of the left gastric vessels. It appears to me, at least from one of the specimens demonstrated today, that those nodes perhaps are not being excised in the operation advocated by Dr. Watson.

One other comment about the longitudinal spread. It almost seems that when the pathologist reports that cancer cells are found at the point of transection of the esophagus, the prognosis is bound to be very good indeed. Recently I had a patient walk into my office who said to me, "You know that this is the thirteenth year since you did the operation." I looked back into the record and, sure enough, the pathologist reported that I had cut through tumor cells in the lymphatic channels.

DR. WILLIAM E. NEVILLE, Cleveland, Ohio.—I want to compliment Dr. Watson on his excellent presentation; we certainly agree with everything he has said. Dr. Clowes and I became interested about two years ago in the use of the colon to replace the esophagus and to date have operated on 14 cases, with four deaths in the immediate postoperative period. We feel, at the present time at least, that the colon offers several distinct advantages; (1) it has an excellent blood supply; (2) it is of sufficient length to reach the neck in case of high resection; and (3) it may be more resistant to peptic ulceration than the jejunum or the stomach.

(slide) This is one of our earlier cases. You can see the proximal suture at the level of the aortic arch. The distal end of the transverse colon is anastomosed to the stomach.

(slide) This is our highest resection for carcinoma to date. The lesion was delivered into the neck and anastomosis performed above the clavicle as demonstrated on the slide on the right.

(slide) This is probably our most intriguing case. This child had a tracheoesophageal fistula which was impossible to anastomose. For this reason, an esophagostomy was performed with a feeding gastrostomy. When the patient was one year of age, we reconstructed the esophagus with the transverse colon. To date he has gained weight and has an excellent nutritional status.

DR. JOHN H. GARLOCK, New York.—In the interest of historical accuracy it is important to remember what the original Torek operation consisted of. It really was not a subtotal esophagectomy at all. In the first place, no attempt was made to find out what was going on below the diaphragm with respect to retrograde lymph node spread and, in the second place, a considerable portion of the esphagus was always left above and brought out to form the upper esophagostomy stoma at a point approximately opposite the left second rib. This was certainly not a subtotal removal.

It is now almost twenty-one years since we started working on this problem and I must say that we have learned a great deal about the life history of this disease. We utilized the Torek operation in the first 16 cases subjected to esophagectomy and it did not take us long to find out that recurrences could occur at the site of the upper esophageal stoma. In the early days, we did not appreciate the significance of this but it soon became evident that this local recurrence was due to submucosal spread proximally. I believe that it is just as important to stress the fact that retrograde spread may occur below the diaghragm even with carcinomas as high as the arch of the aorta. This spread usually involves the nodes along the course of the left gastric artery and in the pericardial area. Any operation which does not include the removal of this lymphatic region below the diaghragm cannot be considered an adequate extirpational cancer procedure. I agree fully with Dr. Watson that it is important to have a wide resection proximal to the tumor. We have been stressing this point for some years now and have gone so far as to advise subtotal esophagectomy for carcinomas of the distal third in order to get beyond the upper limits of the submucosal spread.

It is always interesting to hear about the revival of operations in which other organs are utilized to restore gastrointestinal continuity. Last year, I visited that dynamic Japanese surgeon, Nakayama, and I had many discussions with him and saw him operate a number of times. He has had a high incidence of breakdown due to interference of blood supply of the upper end of the stomach when he utilized an intrathoracic anastomosis In practically every case now he is placing the stomach subcutaneously which is again a rejuvenation of an old operation He effects an almost subtotal esophagectomy, brings the stomach subcutaneously as far as the neck and makes his anastomosis with the esophageal stump beneath the skin He claims that if he gets a breakdown, it is much better to have it under the skin than in the chest and I am sure that everyone here will agree with him It might surprise you to learn that he accomplishes this operation in the brief span of one hour and fifteen minutes

DR WILLIAM L WATSON, New York, N Y (Closing) —I should like to thank those who were kind enough to discuss our report We share Mr Allison's pessimism regarding esophageal cancer in general, and, in going over the results in our 1,700 cases, we were unable to find a single five year survival in the group of cancers located between the thoracic inlet and the aortic arch, these are the cases discussed in this report

Dr Sweet brings out the point that he always explores the upper abdomen first, but of course lesions of the upper one third of the esophagus do not routinely metastasize to the upper abdominal lymph nodes, and if such metastatic lymph nodes are present they do not necessarily contraindicate excisional palliative surgery At our second stage procedure, the upper abdomen is thoroughly explored and regional metastatic lymph nodes are removed

It was good of Dr Garlock to point out the dissimilarity between our operation and the ones so ably done by Dr Franz Torek He is correct, and yet I believe we both desire to give Torek the credit for his pioneer work, certainly the operation of esophagectomy first recommended by Dr Torek could not be called a segmental resection It was more than that—in other words it was a subtotal esophagectomy

CARDIAC SURGERY WITH HYPOTHERMIA AND ACETYLCHOLINE ARREST

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BARRY L. SIEGEL, M.D., AND WILLIAM E. ADAMS, M.D.
CHICAGO, ILL.

TOTAL body hypothermia has been shown to protect vital organs from prolonged periods of oxygen deprivation.[1-3] The suppression of metabolic activity that is the basis for this and the sensitive temperature modalities of cellular enzymatic reactions suggest real hazard associated with the use of temperatures far from body normals. Holding the period of circulatory stasis to a minimum has prevented the appearance of cerebral, renal, and hepatic complications; however, there has been trouble with the heart itself, clinically with abnormal hearts and experimentally with normal hearts. The major complication, and of a consequence the major deterrent to the use of clinical hypothermia, has been the occurrence of ventricular fibrillation.[4, 5] Fibrillation has appeared during cooling and warming; therefore, the hypothermia per se has been considered the major factor causing ventricular fibrillation. Undoubtedly there is an increased sensitivity to fibrillation from the hypothermia. Attempts to obtain precise physiologic data to explain this have shown refractory period variations, retardation of depolarization and repolarization in pacemaker tissue, etc.,[6] but there has been no finding to settle this issue. Hypothermia (to 20° C.) alone does not lead to cardiac failure[7] and oxygenation of the myocardium is more than adequate.[8]

Unfortunately, it has been impossible to have all data associated with controlled ionic and acid-base relationships. In fact, many experiments are such that one cannot even guess the general trend—acidosis, alkalosis, or normality. Our experience is apropos. The generally recommended method of hyperventilation to a state of alkalosis[2, 4] has been associated with considerable presurgery ventricular fibrillation in our experiments, and this hazard increased at the lower temperatures.

Maintenance of a near normal acid-base balance with self-ventilation during cooling and minimal respiratory assistance when the chest was open has altered the picture.[9] Since adopting this method the only animal (of 90) that has had ventricular fibrillation prior to cardiac manipulation and surgery has been one with a heart full of worms. Niazi and Lewis have had excellent results with the use of added CO_2 which helps to maintain normal

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serum pH.[10, 11] Fisher and co-workers[12] have used simple self-ventilation in their studies and have had no ventricular fibrillation until after six and one-half hours of 22° C. hypothermia.

When circulatory stasis has been added, it is our impression that this is the major factor relative to the production of ventricular fibrillation, to the cardiac damage which produces the failing heart, to the rhythm disturbances during warming, and to some postoperative deaths. When the surgical procedure produces a valvular abnormality or coronary insufficiency, a more lethal factor may be introduced.

The heart is protected from loss of coronary circulation by the hypothermia. At normal temperatures the excluded heart will deteriorate in one to three minutes and will rarely tolerate more than five minutes *while still contracting.* The hyperthermic heart (42° C.) will go into lethal standstill within a few seconds after inflow occlusion.

From this point of view, there are three approaches to gain further protection for the heart with hypothermia: (1) stopping or profoundly inhibiting cardiac activity during the period of circulatory stasis to diminish useless metabolic activity, (2) giving oxygen to the myocardium during the cardiotomy time, and (3) decreasing cardiac sensitivity with antifibrillatory drugs.

Combinations are also important, and it is probable that a part of the effect of many antifibrillatory drugs is in their concomitant slowing of cardiac rate (and therefore work).

METHOD

Preparations and procedures were essentially the same for experimental animals and patients. Morphine sulfate was the only medication given prior to surgery. Atropine-like compounds were avoided because they block the effect of the acetylcholine. Ether-oxygen anesthesia was used in amounts just sufficient to produce sleep and prevent shivering. Self-ventilation was allowed to the time of opening the chest, although an occasional animal required episodic assistance to respiration. This maintains a relatively normal acid-base relationship. When the thoracotomy was performed and assisted respiration needed, only 3 cycles were made in each minute (with the temperature between 20° to 26° C.). Inspiratory and expiratory carbon dioxide volume percentages were constantly monitored (at oral level) with a recording Liston-Becker CO_2 meter.* This was especially helpful in judging the character of assisted respiration. After initial problems with excessive and accumulated tracheobronchial secretions and persistent pneumothorax, presumably due to the fact that no atropine was used, repeated intratracheal aspirations were performed during cooling and warming. Such difficulties have not been encountered in the human patients. Cooling and warming were accomplished with a commercial circulating fluid blanket with pump and temperature modifying unit (Therm-O-Rite). A direct reading galvanometer with attached rectal thermocouple was used to monitor temperature. Repeated checking was done with a mercury thermometer. With this slow cooling, the intrathoracic temperatures were quite close to the rectal ones. In clinical cases, excessive cooling of feet and pressure areas was avoided by repeatedly checking temperatures of the skin at these sites and by insulating when low temperatures were obtained. This has been extremely important with infants as peripheral temperatures will fall to 10° C. long before the surgical temperature is attained. Procedures on the patients were performed at 22° to 26° C., in the animals at 20° to 28° C. Limb Lead II electrocardiogram has been used as a monitor throughout the procedures. A plastic catheter cannula was inserted into the femoral artery of the cooled animals for pressure recording. Arterial pressure and electrocardiogram were recorded continuously on a Grass ink-writing electromanometer, a P23D Statham strain gauge has been used as the pressure transducer. Appropriate right, left, or bilateral thoracotomy was performed as needed for the operation. Cardiac exclusion was accomplished by occluding the azygos vein and both venae cavae, halting respiration, allowing the heart to empty, and cross clamping the aorta and pulmonary artery. Acetylcholine chloride was then injected into the aorta proximal to the occlusion in order to infuse it into the coronary system. Following completion of the operative procedure, atropine sulfate was similarly introduced into the aorta, perfused by manual compression through the heart, and then the superior caval and outflow occlusion were removed. As cardiac filling decreased, the inferior vena cava was disoccluded. For dogs of 10 to 15 Kg. body weight, 100 mg. of acetylcholine has been used. Human dosages have ranged from 75 to 100 mg. Perfused blood in either instance has been mixed with 100 mg. of acetylcholine per 500 ml. of blood immediately before use. Atropine sulfate, 0.6 mg., has been given for each 100 mg. of acetylcholine chloride except for that placed in the coronary perfusate.

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*Modified for constant recording and instantaneous calibration

EXPERIMENTAL BACKGROUND

The data relative to protection of the heart by inhibiting its action have been presented in detail elsewhere.[13] The story of the acetylcholine effect is summarized in the bar graph shown in Fig. 1. Twelve dogs were cooled and subjected first to one minute of occlusion alone, and then, following cardiac stabilization, a 10-minute period of occlusion with intracoronary acetylcholine (100 mg.) followed by 0.6 mg. atropine sulfate and disocclusion. The average normal cardiac rate of 164 fell to 71 with the hypothermia (25° C.), remained approximately the same with occlusion alone for the one minute, but fell to an average of 7 per minute during the 10 minutes under acetylcholine; shortly after atropine and disocclusion the average rate returned to 81. Surgical procedures induce added contractions, usually to a total of 10 per minute. Compared to the unmodified heart, the electrocardiogram in these animals shows less abnormality when return rhythm has been attained, and most striking the heart remains pink.

Perfusion of oxygenated blood through the coronary system maintains a good heart for cardiotomy.[14, 15] Only small amounts of oxygen are needed with the hypothermic metabolic inhibition. For example, at 25° C. a dog heart will extract 3 to 4 volumes per cent (aorta to coronary sinus) from a perfusion of 1.5 ml. blood per Kg. body weight per minute. It is difficult to perfuse the small dog heart at less than 1 ml. per Kg. per minute for a prolonged period with a Sigmamotor pump system, but it is clear that even a 0.5 ml. per Kg. per minute will maintain a normal heart. If the heart has been stopped with acetylcholine, added perfusion will initiate cardiac contractions; therefore acetylcholine must be added to the perfusion system to maintain a quiet heart. Such perfusion, minimal quantitatively, still adds procedural problems and blood handling. It also produces a constant though small blood flow into the operative field.

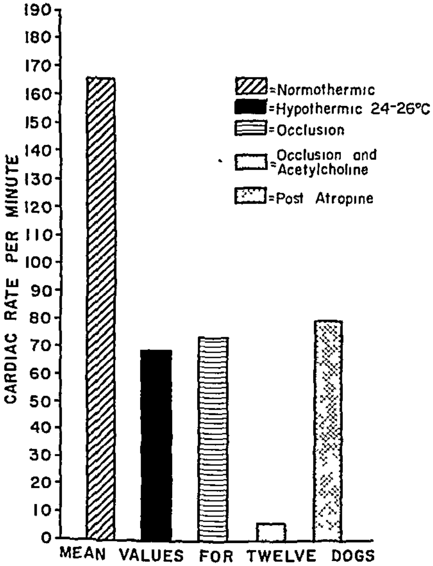

Fig 1.—The effect of acetylcholine on cardiac rate in total circulatory occlusion.

Sixty-two dogs have undergone hypothermia with acetylcholine inhibition of heart activity for periods of time ranging from 5 to 37 minutes. Mortality, for the most part, has been associated with the more strenuous procedures. There has been a high incidence of fibrillation (29 in 62) in most instances following surgical procedures and the majority have been reversible. Intractable (or constantly recurring) fibrillation occurred in 9 dogs, and 4 of these were with direct coronary artery work.

Table I summarizes the data on these animals. General grouping of relative risk procedures has been done to simplify presentation. The average and range for temperature and occlusion time are given for each group. The longest time for occlusion was 37 minutes for a left atrial procedure. Operative deaths were primarily technical in the first two groups and from recurring

TABLE I ACETYLCHOLINE CARDIAC INHIBITION: OPEN CARDIAC SURGERY IN DOGS DURING HYPOTHERMIA

PROCEDURES	NUMBER OF DOGS	AVERAGE LOW TEMPERATURE (CENTIGRADE)	AVERAGE OCCLUSION TIME (MINUTES)	MORTALITY				LIVING, SACRIFICED, OR *PNEUMOTHORAX	VENTRICULAR FIBRILLATION	
				OPERATIVE	WARMING	RELATIVE TO SURGERY	TOTAL		REVERSIBLE	INTRACTABLE
Occlusion Right and left atriotomy Aortotomy	33	24.6° (22°-27°)	12 (5-37)	1	5	1	7	26	8	1
Right and left ventriculotomy	21	24.7° (22°-28°)	13 (9-19)	5	5	5	15	6	10	4
Open coronary artery	8	23 7° (20°-26.5°)	14 (9-21)	5	1	1	7	1	2	4
									29	
Total	62	24.8° (20°-28°)	13 (5-37)	11	11	7	29	33	20	9

*See text.

fibrillation in the coronary artery group. Deaths during rewarming were from hypotension, arrhythmia, and undiagnosed pneumothorax in the first group. Many in the ventricular group were from arrhythmias. Deaths "related to surgery" are from the effects of blood loss, arrhythmias, and 3 were from sudden reactions at the time of extubation following rewarming when the situation was otherwise quite well. Because of this, we now give 0.6 mg. atropine sulfate intravenously 10 to 15 minutes before extubation. Marked and persistent pneumothorax has appeared with the abandonment of atropine medication prior to cooling. There are additive effects from the restricted respiration used with the open chest and excessive inflation pressures used to re-expand the lungs. A few dogs, otherwise doing quite well, were found dead the morning after the day of surgery from the effects of pneumothorax. These have been included in the survival group (see Table I). The use of periodic tracheal suction during the cooling and warming periods, constant chest suction during warming, and avoidance of excessive intratracheal pressures when expanding the lungs after the cardiac procedure, have obviated this complication. Excessive secretions and pneumothorax have not occurred in the few clinical cases.

Seven dogs had prior implantation of radioactive yttrium^{90} oxide pellets into a portion of the left ventricular myocardium or along the anterior descending branch of the left coronary artery. After the procedure all animals returned to a good rhythm and were sacrificed for the heart specimen. One animal was moderately hypotensive, but did not fail in a long waiting period before sacrificing. Compression was not used because the heart was to be preserved for study. This would suggest no exaggerated sensitivity of the damaged heart to hypothermia and cardiac inhibition during circulatory stasis.

The first group includes cardiac exclusion, right and left atriotomy, and ascending aortotomy. Although these can be carried out successfully under hypothermia alone, each was considerably safer and easier under these circumstances in our laboratory. Increase of the reasonable time limit for the intracardiac surgery was an immediate advantage. Most right atrial work was the production and closure of an interatrial septal defect, occasionally only the atriotomy was performed for the purpose of implanting radioactive yttrium^{90} oxide pellets into the atrioventricular nodal area. In the left atrium two-thirds closure of the mitral valve by direct suture was the only operation, however, the exposure is surprisingly good and any combined valve and septum or similar work could be done. Only a mock procedure on the aortic valve was performed from the open ascending aorta. In the dog exposure of the coronary orifices for any direct work is only fair from this site.

An interventricular septal defect was made and closed by either suture alone or suture with an Ivalon sponge in the right ventriculotomy group. A limited endocardial resection was performed in the animals having left ventriculotomy. The operative deaths were usually technical, such as making a high septal incision and cutting the aortic valve or interfering with the right conduction bundle, these animals developed intractable ventricul

TABLE II. ACETYLCHOLINE CARDIAC INHIBIT

PATIENT	DIAGNOSIS	PROBLEM	PROCEDURE	TEMPERATU (CENTIGRAD
16 years ♀	Ostium primum Interatrial defect	Bacterial endocarditis, 2 × Cardiac failure Left-to-right shunt	Suture closure	23°
4 years ♀	Ostium secundum Interatrial defect	Repeated pneumonias and infections Moderate cardiomegaly Left-to-right shunt	Suture closure	22.5°
1 year ♂	Atrioventricularis communis	Cardiac failure Retardation	Suture closure	23°
30 years ♂	Aortic valvular stenosis	Coronary insufficiency Cerebral ischemia	Open aortic valvulotomy	26°
13 years ♀	Corrected transposition aortic chamber ≍ common ventricle	Cyanosis Cardiac failure Respiratory distress Retardation Huge shunt	Incomplete formation of interventricular septum with Ivalon sponge	24° Perfusion of onary arte

the inhibition in about three minutes. Motion effects prevented accurate electrocardiographic counting of contractions, but usually there were 2 or 3 to 10 contractions per minute. Reversal was accomplished in all but the third case. An irreversible standstill with a heart that suggested a potassium-arrested heart occurred near the end of the procedure, and only calcium ions produced slight activity with some tone. All efforts at resuscitation were ineffective. Autopsy demonstrated that a technically poor closure had been obtained. With closure of the ostium primum interatrial defect it was difficult to fill the left heart and air embolism was encountered with ventricular fibrillation at disocclusion. Defibrillation was accomplished.

At no time did these patients evidence arrhythmia during the cooling period. The blood in the surgical field was visibly well oxygenated and the hearts were quite pink at cardiotomy. In the third case continuously recorded ear oximeter values showed 91 to 93 per cent blood oxygen saturation during cooling and bilateral thoracotomy. Following restitution of circulation the saturation was about 80 per cent and remained at 85 to 90 per cent during warming.

From a technical point of view the work in the first 4 cases was done in a dry, quiet field. In the ostium primum heart it was possible to do quite careful suturing on the septal brim above the nodal and conduction tissue, and this patient has shown no rhythm disturbance in the six months since surgery. The aortic valvulotomy would not have been too difficult with any method, but under these circumstances a good valvulotomy without regurgitation, cusp damage, or embolic danger was easily performed, and the immediately modified murmur disappeared entirely by the fourth postoperative day.

Open Cardiac Surgery in Human Beings During Hypothermia

CARDIAC EXCLUSION TIME (MINUTES)	ACETYLCHOLINE (MG.)	COOLING TIME (HOURS)	WARMING TIME (HOURS)	RHYTHM	RESULTS REMARKS
13½	100	6⅔	4	Ventricular fibrillation (air embolism)	Grossly complete closure, living and well at 6 months, no arrhythmias (operation 11/29/55)
9	80	6½	3¼	Normal	Grossly complete closure, living and well at 5 months
17	75	2⅔	—	*Cardiac standstill*	*Operative death, cause of standstill undetermined,* technically a poor closure
4½	100	7	5½	Normal	Cerebral edema 1 day, murmur gone by 4 days, died 7 days massive pulmonary embolus, autopsy showed excellent valvulotomy
22	100 +	4½	2½ (Incomplete)	Normal	Died while warming (34°) from bleeding due to coagulation defect

In the fifth case where coronary perfusion was performed, the heart was quiet, but the presence of the returning blood proved strikingly different from the other bloodless cardiotomies. With minimal contractions and the low temperature it was conspicuous that the cardiac venous blood was red shortly after the perfusion was started (at only 2 ml blood per Kg body weight per minute).

DISCUSSION

Open heart surgery under hypothermia has been a reality because of the work of Bigelow,[1] Lewis,[3] and Swan,[4] and their co-workers. These studies are *complementary to existing techniques and are intended for further pro*tection of the heart and for increasing safe operative time. From an experimental point of view, it is suggestive that some added antifibrillatory drug or mechanism could be added for at least the more difficult and prolonged procedures.

On the one side investigators have found that a small amount of coronary (and brain) perfusion of oxygenated blood increases the safety of hypothermia for cardiac procedures and, on the other, decreased blood flows are being used with normal temperature extracorporal pump oxygenating systems.[16] We might eventually expect a common meeting place for both methods with *moderate cooling and extremely low flow rates from an extra*corporal circuit. Short cooling time, long operative time, and simplified apparatus would result. Inhibition of cardiac activity would also be additive under these circumstances. However, open procedures upon and eventually replacement of the aortic valve seem possible.

coronary work may also be found to be dependent upon a quiet heart with circulatory stasis, a situation which has been demonstrated to be possible with this modification of hypothermic surgery.

CONCLUSIONS

1. Intracoronary acetylcholine markedly inhibits cardiac activity during cardiac exclusion under hypothermia. Its effect is readily reversible with atropine.

2. Surgical procedures in the four cardiac chambers, the open aorta, and on the coronary arteries can be performed in dogs with this method.

3. Direct vision atrial and aortic cardiac surgery have been performed in human beings with acetylcholine inhibition of cardiac activity under hypothermia.

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DISCUSSION

DR. CONRAD R. LAM, Detroit, Mich.—A year ago, Dr. Geoghegan, Dr. Lepore, and I presented before this Association a paper entitled "Induced Cardiac Arrest for Intracardiac Surgical Procedures" (J. Thoracic Surg. 30: 620, 1955). You will recall that we used potassium chloride to produce this arrest, and the recovery phase was almost invariably accompanied by ventricular fibrillation. We immediately began to seek a way to avoid this complication and last November we began to use acetylcholine.

(slide) This is the record of one of the animals. We see the normal aortic pressure and Lead II of the electrocardiogram. This is the record taken at the time of vena caval occlusion and after the acetylcholine was injected, the heart was stopped at this point. Here we have complete asystole. At this point the coronaries were perfused with oxygenated blood, and 3 minutes later a slow contraction occurs, then 30 minutes later a normal contraction. I felt we should wait for the availability of an oxygenator before trying this on a patient and for that reason there was some delay.

(slide) This is the electrocardiographic record of a 14 pound patient 13 months old, with an interventricular defect, who had acetylcholine arrest of the heart for 15 minutes. Here is the normal electrocardiogram. This is the record of 15 minutes of arrest and 30 seconds after the clamp was removed from the aorta and the oxygenated blood allowed to flow in. You see the first contraction, the second one, after one minute, 2 minutes and the record on the first postoperative day.

(slide) This shows the picture of this boy on the second postoperative day. The opening in the ventricle was closed with a perfectly dry field and a perfectly still heart. The combination of a suitable oxygenator plus arrest with some drug such as acetylcholine, seems to be the answer to this form of intracardiac surgery.

DR. HENRY SWAN, II, Denver, Colo.—Late in 1954, on the basis of our laboratory experience, we began to use clinically the relatively short acting anticholinesterase prostigmine, which we gave by coronary perfusion after circulatory occlusion had been set up. We now have had the opportunity to observe the action of this agent on about 75 patients, and we continue to believe that it is valuable. Prostigmine, in the doses that we use, markedly slows the heart but does not actually stop it. Heart rates of the magnitude of from 3 to 25 a minute persist throughout the operative procedure. We felt at first, and I am interested in hearing of the work this morning, that acetylcholine would have too short an action because it is so rapidly destroyed. Yet on the basis of what we have heard today I believe this is not necessarily true. Following prostigmine, as Dr. Lam has said, the heart starts readily again when circulation is restored.

With regard to the use of hypothermia alone, we have been gradually exploring the perimeters of that as a safe technique for opening the heart, and we must of course admit that the heart does undergo a continuing and progressive hypoxia during the period of circulatory occlusion. The protection of hypothermia is relative, of course, and is not absolute, so that we cannot expect it to be of indefinite duration with or without stopping the heart. We have gradually come to use a lesser range of hypothermia than when we began, because we found that we did not encounter ventricular fibrillation in these patients under the temperature of 28° C., rectal temperature. So that we have gradually *come to use the range from about 28° to 31° C., and we feel that the brain will be pro*tected for periods up to 12 or 15 minutes at this temperature, we think that 10 is fairly safe and 8 very safe indeed. We have had no cerebral damage in using this range.

Currently, then, we are recommending that the range of temperature for clinical application of hypothermia alone be in the neighborhood of 28° to 31° C. because of the relative absence of serious arrhythmias, with occlusion times of the heart not to exceed 8 minutes, and with the heart under the influence of an anticholinesterase with the coronary circulation occluded.

DR. PETER V. MOULDER, Chicago, Ill. (Closing).—I should like to show one slide that brings out a point relative to the discussion of Dr. Swan. The slide demonstrates the effect of cardiac occlusion *for 50 minutes. Before occlusion there* is a good pressure, normal electrocardiogram, after occlusion, no pressure, then following intracoronary acetylcholine (100 mg.) the electrocardiogram shows cardiac arrest, the next partition shows at 10, 30, and 50 minutes, no electrical activity (or cardiac contractions). The last part shows 5 or 6 minutes after disocclusion with a relatively normal electrocardiogram and a good effective pressure. This was one of those fortunate experiments in which virtually no contractions occurred during the entire 50 minutes. The heart will be resuscitated without the atropine, responding to the filling of the heart with blood and coronary blood flow, but a ventricular or nodal rhythm will persist for a considerable period. The atropine produces rapid reversion to a normal sinus mechanism.

cough developed, associated with substernal soreness. The next day some scanty viscid sputum was raised with difficulty. On physical examination, scattered squeaking, and occasional sonorous, râles were heard. Crackling râles were present at both bases. The breath sounds were bronchovesicular.

Forty-eight hours after the onset of this illness, trypsin therapy was instituted in the following manner: one-half cubic centimeter of Parenzyme was given intramuscularly daily, plus one buccal trypsin tablet every four hours. When examined the next day the patient appeared far more comfortable. The temperature was normal, the cough was much softer, the sputum was copious and easily raised. Therapy was discontinued after another twenty-four hours.

2. *Chronic Bronchitis.*

N. B., a 34-year-old housewife, had a dry, irritative cough for eight years, which became aggravated by cold weather or following upper respiratory infections. In the past year, following an episode of severe bronchopneumonia, the coughing became worse, sputum became scanty and mucopurulent. There was an occasional episode of paroxysmal coughing of several minutes' duration, persisting until sputum was raised. On physical examination, chest expansion was diminished. Scattered areas of sonorous, squeaking, moist râles were heard, which cleared after a vigorous cough.

Treatment consisted of one-half cubic centimeter of Parenzyme intramuscularly plus one buccal trypsin tablet every four hours. Four days later the following changes were recorded: (1) the sputum was thinner, more abundant, and easily raised, (2) the cough was more loose, (3) only an occasional crackling râle was heard, and (4) the patient felt considerably improved and was eating and sleeping better. After the first week, intramuscular Parenzyme therapy was discontinued and the patient was maintained on one buccal tablet, 3 times a day. This regimen was discontinued after four months, when the patient stated she coughed only occasionally and chest examination was negative.

3. *Chronic Bronchiectasis.*

P. M., a 37-year-old Puerto Rican man, was admitted to Metropolitan Hospital because of shortness of breath and ankle edema of three days' duration. He had been coughing for eight years, occasionally expectorating a large amount of sputum. At various hospitals he had been told he had bronchial asthma. He had been followed in an outpatient department of an outside hospital with ephedrine tablets, and had improved until three days prior to this admission. On physical examination, the temperature was 99° F., apex rate 108, radial rate 78, blood pressure 105/60. He appeared malnourished and dyspneic. A fetid odor permeated his room. The lungs were emphysematous, with hyperresonance noted in both lung fields. Many moist râles were present in both bases. There was a sinus tachycardia on ECG. Chest film showed extensive bilateral bronchiectasis. The liver was 1½ fingerbreadths below the costal margin. A three plus ankle edema was present. Prominent clubbing of the fingers and toes was evident.

Laboratory findings: Urine specific gravity was 1.020, and was negative for sugar, pus, or albumin. Blood urea nitrogen was 16 mg. per cent, albumin-globulin ratio was 2.8/3.8; total protein, 6.6; cephalin flocculation test was negative. Thymol turbidity test was 1.4 units, and hemoglobin, 13.5 Gm. White blood count was 8,100 to 17,200; eosinophil, 2 per cent; red blood count, 4.75 million. A Mazzini test was negative. Sputum cultures revealed intermediate coliform organisms, sensitive to Aureomycin, Chloromycetin, and Terramycin. *Proteus vulgaris* and *Alcaligenes faecalis* organisms were recovered. Sedimentation rate was 1.0 mm. per 15 minutes and 0.0 mm. per 15 minutes. ECG showed right ventricular preponderance.

For the first two weeks of his present hospital stay, treatment consisting of Aureomycin, penicillin, and Chloromycetin, was ineffectual. He then was placed on buccal trypsin therapy, one tablet every three hours for three days, and then every six hours for maintenance.

After seventy-two hours of buccal trypsin therapy the following changes occurred: (1) the fetid odor disappeared, (2) coughing was increased, but more loose, (3) the sputum was much thinner and more abundant, and (4) expectoration was easier. On postural drainage large quantities of mucopurulent material were evacuated.

This patient maintained the above level of improvement while on buccal trypsin for an additional two weeks. Buccal trypsin therapy was then terminated. After ten days without trypsin, all the previous symptoms gradually returned.

4. *Bronchopleural Fistula.*

L. N., a 24 year old Puerto Rican seamstress, was referred to the hospital from the chest clinic with a diagnosis of chronic pneumonitis and lung abscess involving the left lower lobe. A lobectomy was performed, but the postoperative course was complicated by a profuse purulent discharge accompanying diffuse cellulitis of the operative site. This was followed in three weeks by a bronchopleural fistula. Purulent drainage was profuse and impossible to control with antibiotics, local lavages, and topically applied Varidase (streptokinase). Trypsin therapy was started consisting of two 2.5 mg. Parenzyme injections plus one buccal trypsin tablet every four hours.

Twenty four hours later the fistulous discharge was considerably thinner and less abundant. Forty eight hours later, there was definite decrease in intensity of the redness involving the entire fistulous tract. At the end of one week maintenance trypsin therapy was instituted with one buccal tablet every four hours. Two weeks later the drainage from the wound was very scanty and mucoid in character. Three weeks later the patient was discharged, at which time the previously necrotic material lining the fistulous tract was replaced by healthy, abundant granulating tissue.

DISCUSSION

Except for two reports on parenteral trypsin,[10, 11] all previous studies on enzyme therapy in respiratory tract infection were based upon intrapleural or aerosol administration.[1-9] In this study, an intramuscular preparation (Parenzyme) and buccal trypsin tablets were employed. The difference between parenteral (Parenzyme) and topical (aerosol) given trypsin are significant. An average single dose of trypsin given by nebulizer is 100 mg.; in one report the single dose was 800 mg. of trypsin.[1] Each dose of Parenzyme contains only 2.5 mg. of trypsin, the buccal tablet also contains 2.5 mg. trypsin.

Enzyme dosage in topical (aerosol) therapy is high since there is direct enzyme substrate interaction, and the extent of protein substrate depolymerization *is a direct function of the quantity of enzyme introduced.* The dose of parenterally given trypsin on the other hand is small, since the physiologic action of parenteral trypsin seems to be activation of the patient's own proteolytic enzyme system, i.e. the conversion of precursor "plasminogen" into the active enzyme "plasmin."[18, 19] The enzyme protein substrate complex following parenteral trypsin is a *plasmin* protein substrate interaction, unlike the *trypsin* protein substrate reaction mixture which characterizes aerosol administration.[20]

Since very small trypsin quantities constitute each dose of parenteral trypsin the rather unpleasant and occasionally serious consequences of massive trypsin aerosol doses are avoided. At no time in this study did we encounter any of the following side effects associated with aerosol enzyme therapy: dyspnea, chills, fever, hoarseness, nasal and eyelid irritation.

In order to understand the physiologic role of trypsin in reversing inflammation one should think in terms of a dynamic equilibrium between proteolytic enzymes and protein macromolecules.[21] From time immemorial it was recognized that an area of acute localized inflammation contained highly viscous exudates. Recent animal studies[22] suggest that following parenterally given trypsin, there is correction of a proteolytic enzyme-protein macromolecular substrate imbalance in the area of local tissue injury. There then follows reduction in viscosity of edema fluid,[23, 24] purulent exudates and lymph, with rapid cleansing of necrotic debris. Ehrich[25] defines inflammation as a "disturbance in homeostasis." Our studies suggest that one of the fundamental homeostatic disturbances in inflammation is the impaired proleolytic enzyme-protein substrate equilibrium. In keeping with this viewpoint, clinical observations made in this study suggest that patients with signs and symptoms of respiratory tract infection benefit from trypsin therapy following enzymatic modification of excessively long chained protein macromolecules in the exudates of inflamed bronchial or pulmonary tissue. This would explain the reduced viscosity, tenacity, and inspissation of respiratory secretion following buccal trypsin and Parenzyme therapy.

It appears that buccally and intramuscularly given trypsin adequately corrects fundamental proteolytic enzyme-protein substrate abnormalities in respiratory tract infection, and as a direct consequence there is a significant decrease in the viscosity and tenacity of respiratory secretions.

SUMMARY AND CONCLUSIONS

In clinical conditions associated with thick, tenacious, respiratory secretions, trypsin therapy (intramuscular Parenzyme combined with buccal trypsin tablets) has the following effects:

1. The sputum becomes thinner, more abundant, easier to raise.
2. The cough becomes more loose, more productive.
3. Accelerated granulation occurs in bronchial ulcerations and bronchopleural fistulous tracts.
4. In chronically ill patients, there appears weight gain, improved appetite, improved sleep and sense of well-being.
5. Acutely ill patients show rapid resolution of inflammation, with early subsidence of cough and substernal burning.
6. In this study, intramuscular trypsin (Parenzyme) and buccal trypsin were used. For long-term maintenance therapy, buccal trypsin alone was employed. The incidence of side effects was low.

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FUNCTIONAL ANATOMY OF THE NORMAL MITRAL VALVE

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ROBERT THOMPSON, M.D.***
CHICAGO, ILL.

THE opening of a new field of surgical endeavor often arouses interest in the detailed anatomy of the involved part of the body. As a result of such studies, current notions may be so changed and extended so as to understand better the morphologic structures of the organ and to provide a scientific basis for its function. The impetus given to mitral valve surgery in the course of the last few years has prompted a thorough revision of our knowledge concerning the anatomy of the normal mitral valve. The classical description of the mitral valve found in the textbooks of anatomy is inadequate for the need of the cardiac surgeon. Similarly, the importance of the valvular structures and the myocardium in the mechanism of valve closure requires a new appraisal in view of recent observations.

It is the purpose of this study to focus attention upon certain anatomic features of the normal mitral valve and their significance in the mechanism of valve closure.

MATERIAL AND METHODS

One hundred and five normal hearts were studied. They were from 60 men and 45 women between the ages of 19 and 65 years. The specimens were, for the great majority, preserved in 4 per cent solution of formaldehyde. They were chosen from cases in which there was no evidence of cardiac disease, except for a small number that exhibited a moderate degree of coronary arteriosclerosis.

In each heart a detailed examination was made of the valve leaflets, mitral ring, chordae tendineae, and papillary muscles. Measurements of various elements associated with the valve apparatus were taken, namely, (1) the diameters and the circumferences of the orifice, (2) the surface area of all valve leaflets and junctional tissue, (3) the height of each single valve leaflet measured in the central portion, from the apex to base, (4) the breadth of the single valve leaflet at the line of insertion at the valve ring, and (5) the depth, that is, the perpendicular measurement from the free edge to the valve ring, of the junctional tissue when this had not become differentiated into valve leaflets.

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A pair of dividers and a metric ruler were used for the linear measurements The surface area was obtained by planimetric integration of the valvular tissue, carefully divided with tiny scissors from its attachments to the valve ring and to the chordae tendineae This was done in 16 fresh hearts, 8 female, and 8 male specimens The greatest care was exercised in preserving the dimensional figures found in situ when calculating the valvular tissue surface area In other words, during the process of planimetric integration, we tried to neutralize the overstretching tendency of the excised valvular tissue by keeping the same figures as far as circumference, the height and the breadth of the leaflets, and the depth of junctional tissue were concerned

THE NORMAL MITRAL VALVE APPARATUS

The normal mitral valve apparatus is composed of various structures including the mitral ring, the valve proper, the chordae tendineae, and the papillary muscles

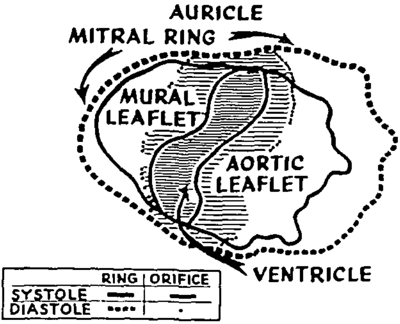

Fig 1 —Diagram demonstrate
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The American Journal of Medicine

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The Mitral Ring —The mitral (atrioventricular) ring or annulus is an important part of the skeleton of the heart[1] It is an anteriorly incomplete circular, and fibroelastic structure It represents the dividing line between the atrial and ventricular musculature from the eighth week of intrauterine life on and appears in the embryonic heart as a result of the crowding together of the connective framework of the organ The ring's upper border is the point of origin of atrial muscular fibers and its lower border is the point of origin of the ventricular musculature It has recently been shown that the atrioventricular annulus decreases its diameter during each systolic contraction" (Fig 1) This event, which takes an effective part in the closure of the normal mitral valve, is probably the result of the systolic contraction of the deep bulbo and sinospiral muscles with the superficial bulbospiral muscle assisting in a minor role In the experimental animal, the impression is gained that the orifice is completely obstructed during the late stage of the cardiac systole by the sphincterlike action of the annulus

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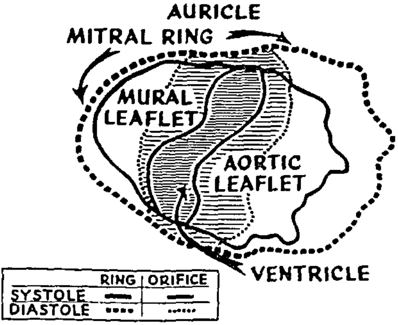

Fig. 1.—Diagram demonstrates the [illegible] mitral ring and changes in contour of lumen in systole and diastol[illegible] litions the atrium and the ventricle are bloodless. "Inspite of t[illegible] n normal it is remarkable to see how much valvular and ring f[illegible] (Hurwitt). (Courtesy The American Journal of Medicine, February, 1953.)

The Mitral Ring.—The mitral (atrioventricular) ring or annulus is an important part of the skeleton of the heart.[1] It is an anteriorly incomplete, circular, and fibroelastic structure. It represents the dividing line between the atrial and ventricular musculature from the eighth week of intrauterine life on and appears in the embryonic heart as a result of the crowding together of the connective framework of the organ. The ring's upper border is the point of origin of atrial muscular fibers and its lower border is the point of origin of the ventricular musculature. It has recently been shown that the atrioventricular annulus decreases its diameter during each systolic contraction[2] (Fig. 1). This event, which takes an effective part in the closure of the normal mitral valve, is probably the result of the systolic contraction of the deep bulbo- and sinospiral muscles with the superficial bulbospiral muscle assisting in a minor role. In the experimental animal, the impression is gained that the orifice is completely obstructed during the late stage of the cardiac systole by the sphincterlike action of the annulus.

TABLE I. MEASUREMENTS (IN CM.) OF NORMAL MITRAL VALVES (105 HEARTS)

STRUCTURES MEASURED	MEN (60 SUBJECTS)				WOMEN (45 SUBJECTS)			
	HEIGHT		BREADTH		HEIGHT		BREADTH	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
Aortic leaflet	2.4	3.2 - 1.9	3.7	4.5 - 2.5	2.2	2.7 - 1.8	3.3	4.2 - 2.4
Ventricular leaflet	1.4	2.5 - 1.0	3.3	4.1 - 2.5	1.2	2.4 - 0.8	3.0	3.6 - 2.3
Anterior accessory leaflet	1.1	1.8 - 0.8	1.5	1.8 - 1.1	1.0	1.3 - 0.7	1.2	1.6 - 1.0
Posterior accessory leaflet	0.9	1.2 - 0.6	1.1	1.5 - 0.8	0.9	1.0 - 0.7	0.8	1.2 - 0.7
Anterior junctional tissue	0.8	1.2 - 0.6	1.7	2.4 - 0.7	0.7	1.1 - 0.6	1.5	2.1 - 0.7
Posterior junctional tissue	0.7	0.9 - 0.5	1.3	1.8 - 0.7	0.6	0.8 - 0.4	1.2	1.6 - 0.7
Circumference of valve ring			10.0	11.5 - 8.5			9.0	10.5 - 8.0

The outer aspect of the mitral annulus constitutes the deepest part of the atrioventricular groove on the external surface of the heart. The mitral valve takes origin as a continuous veil from the inner aspect of the ring and inserts around the entire circumference of the mitral orifice.

In this study we found that the circumference of the mitral annulus was in average 10 cm. (range: 8.5 to 11.5 cm) in the male specimen, and 9 cm. (range: 8 to 10 5 cm.) in the female specimen (Table I). The readings obtained were very seldom found at variance with these figures

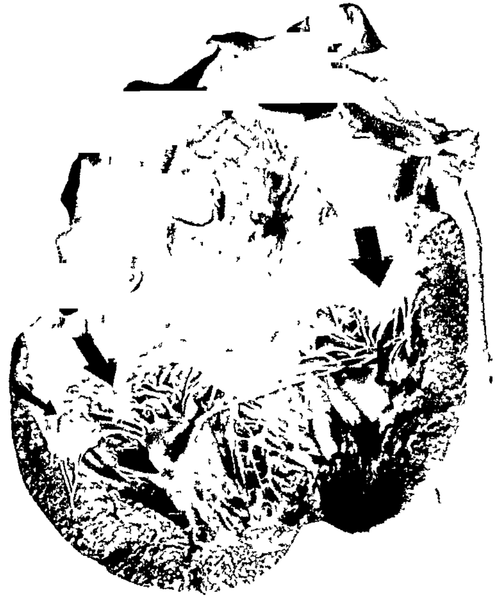

Fig 2—Photograph of a human mitral valve showing anterior and posterior [illegible] leaflets Two big arrows indicate the position of these minor cusps The small [illegible] to the ventricular leaflet (Institute of Pathologic Anatomy, University of [illegible] School, Italy, Autopsy No 2597.)

The Mitral Valve Proper.—The mitral valve is represented by a [illegible] veil of valvular tissue attached as a muff to the entire circumference of the atrioventricular annulus Its free edge is split by indentations [illegible] reaches the mitral annulus These clefts divide the valvular [illegible] major leaflets which are always present and into two min[illegible] not invariably present. These minor cusps, when [illegible] the junctional tissue (Fig. 2).

The valve tissue consists of a fibroelastic texture covered on the atrial and ventricular aspect by a coat of endocardium. The so-called fibrous skeleton which gives strength and shape to the valve is furnished by a layer of connective tissue protruding from the inner aspect of the mitral ring. Important contributions to the valve-supporting framework are the chordal insertions. Rusted and his associates[3] noted that the chordal insertions passed through the substance of the leaflet for a considerable distance. This particular arrangement, as pointed out by the Mayo Clinic group, is often seen on the transilluminated posterolateral leaflet, but more often a fibrous band running along the margin of closure is seen in this leaflet. This fibrous structure can be considered as the point of insertion of the chordae. Neither the junctional tissue nor other additional valve leaflets show any such arrangement of their connective layers.

The two major cusps are attached to the ring in such a way as to be in anteromedial and posterolateral locations. The anteromedial cusp has been referred to as the anteromedial, aortic, septal or greater leaflet. The posterolateral has been designated as the posterolateral, ventricular or lesser leaflet. The major axis of the mitral orifice is consequently directed obliquely forward from right to left.

The Anteromedial or Aortic Leaflet.—The aortic leaflet is the most important from the anatomic as well as the physiologic standpoint. Table I shows the linear measurements of the various valve leaflets. Table II lists the surface measurements of the same structures, obtained by planimetric integration of the removed valvular tissue. The aortic cusp is by far the largest. It exceeds every other leaflet in height and breadth at the mitral ring. Its surface area gives a better idea of the importance of this cusp, because it is equal to almost one-half of all valvular tissue surface area.

TABLE II. MEASUREMENTS (IN MM.^{2}) OF NORMAL MITRAL VALVE (16 HEARTS)

STRUCTURES MEASURED	MEN (8 SUBJECTS)		WOMEN (8 SUBJECTS)	
	AVERAGE	RANGE	AVERAGE	RANGE
Aortic leaflet	651	833 - 427	563	714 - 413
Ventricular leaflet	384	532 - 270	334	456 - 413
Anterior accessory leaflet	227	257 - 193	203	220 - 183
Posterior accessory leaflet	136	148 - 110	120	128 - 112
Anterior junctional tissue	171	200 - 129	144	171 - 125
Posterior junctional tissue	92	110 - 70	78	94 - 67
Valvular tissue area	1398	1770 - 1000	1220	1518 - 970
Mitral orifice area	793	1020 - 572	642	875 - 490

The anteromedial cusp is roughly triangular in shape and, in our experience, its free edge has never been found split.

It is the only dividing structure between the mitral and the aortic orifice. Directly inferior to the aortic canal, it constitutes an integral part of the outflow tract of the left ventricle. Due to this anatomic location, a considerable portion of its function is believed to be the direction of the flow of blood toward the aorta. This has been described by Harken[4, 5] as the aortic baffle. In other words, the leaflet apparently acts as a watershed which deflects the blood toward the aorta in the ejection phase of the ventricular contraction.

Close anatomic observation of the normal heart as well as experimental investigation of the valvular function would not be in favor of this view. The leaflet has the greatest importance in the closure of the mitral valve, but it has no baffling action on the blood flow. Indeed, the blood driven forcefully from the inflow into the outflow tract has no other outlet but the aortic orifice, since the mitral valve is, at this stage of the systole, hydraulically closed. The physiologic lines of progression upon which the blood is forced out into the aorta run directly from the apex of the heart to the aortic canal. The contribution of the anteromedial leaflet to the formation of these lines of direction is certainly not greater than that of the interventricular septum or the anterior left ventricular wall. The last mentioned two structures together with the septal cusp constitute the walls of the outflow tract of the left ventricle. If a defect is produced in the aortic leaflet, as it was in the case of the famous patient of Dr. Adam,[6] or as it is possible to do in experimental surgery, a great valvular incompetence ensues since here there are no compensatory mechanisms likely to limit the mitral reflux. Likewise, a defect of the interventricular septum will permit an escape of blood into the right ventricle. The two situations, the mitral reflux and the escape of blood through an interventricular septal defect, are indeed dynamically analogous since both are governed mainly by the intracavitary pressure. On the other hand, the muscular fibers of the outflow tract appear to play an important role in giving a definite direction to the blood flow. This fact is demonstrated by the position of the left ventricle in the cases of prevailing hypertrophy of the left ventricular outflow tract.[7]

The Posterolateral or Ventricular Leaflet.—The smaller ventricular leaflet is not as important as the aortic leaflet, but by no means should it be disregarded in the mechanism of valve closure. This is confirmed by experimental and clinical facts. The posterolateral cusp is roughly equal to one-third of all the valvular tissue surface area. Its breadth at the line of insertion is only a few millimeters less than that of the aortic leaflet, while its height is almost one-half that of the anteromedial cusp (Table I). The contour is usually quadrangular with sloping sides and its free edge is often notched. However, the notching is seldom deep enough to be mistaken as a cleft separating the posterolateral leaflet from an additional cusp. The importance of the ventricular leaflet in the closure of the normal mitral valve seems to have been generally underestimated.

It was originally Marc Sée, a French physiologist, who, in 1875, thought that the complex mechanism of the normal mitral valve function could be simply described as an unpretentious or moderate systolic and diastolic swinging movement of the septal leaflet.[8] According to Sée, the contraction of papillary muscles would cause the anteromedial leaflet to act like a "curtain stretching obliquely from the right half of the mitral ring and across the orifice, which would remain entirely hidden." At the same time, the posterolateral ventricular wall "would march" toward the septal leaflet and come into contact with its free margin. In diastole, the aortic leaflet would swing back opening the valve. Consequently, the ventricular leaflet appeared to be a worth [illegible] as far as the mechanism of the mitral valve closure was concerned. The perivalvular space was thought to be entirely obliterated in systole by the posterior ventricular wall moving toward the aortic cusp.

This old and forgotten theory has recently been revived by Harken and co-workers,[4, 5] and Gorlin and Dexter,[9] with the additional notion by Harken that "the posterior leaflet is squeezed and buttressed by the posterolateral wall of the left ventricle in systole (Fig. 3). In diastole, the myocardium swings away from the normal veil-like posterior mitral leaflet." Brock[10] has also admitted that this mechanism of closure may well happen sometimes. It was on account of this view that Harken[4] operated upon his first patient with unsatisfactory results.

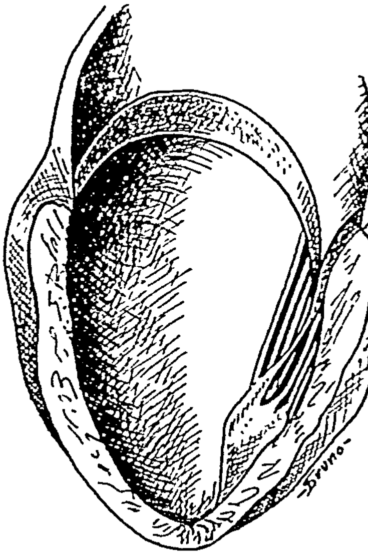

Fig. 3.—Closure of normal mitral valve according to the theory of Marc Sée, revived by Harken. The anteromedial leaflet acts like a "curtain" stretching across the orifice, which remains entirely hidden. The posterior ventricular wall moves in and buttresses the posterolateral leaflet.

We have tried to evaluate the anatomic and functional importance of the ventricular leaflet with experimental, morphologic, and clinical observations. From our investigation, it would appear that the theory of Sée and Harken can hardly be supported.

In the first place, the digital exploration of a normal human mitral valve by one of us (M. A. C.), in a mistaken preoperative diagnosis of mitral stenosis, revealed a remarkable billowing effect of the ventricular leaflet toward the left atrium. This had been felt in the horse's heart many years ago by the French physiologist Chauveau, who spoke of "dôme multiconcave."[11] The ventricular leaflet could be forced out into the atrium only by the blast of blood squeezed into the perivalvular space, like the wind fills out a sail. The same could not be produced by the ventricular wall being pushed against and buttressing the posterolateral leaflet. Moreover, the digital pressure on the ballooned-out ventricular leaflet produces a feeling of resilience like that of squeezing a fluid-filled bag which would hardly be felt were the muscular wall responsible for the bulging. In addition, this same maneuver causes an immediate mitral reflux, which further suggests that the perivalvular space is not obliterated in systole.

Second, the chordae tendineae of third order, which constantly connect the ventricular leaflet with the ventricular wall, would be devoid of any importance if we were to admit that the heart wall buttresses the leaflet. As we will describe in more detail later, these chordae are there to prevent the eversion of the leaflet when the systolic thrust forcefully distends it with blood.

And third, even though the exploring finger in the heart of a dog gives one the impression of the myocardial wall supporting the ventricular leaflet, a defect in this cusp tends in no way to be closed and causes a prompt regurgitation. This would not be the case if the closure of the mitral orifice were due only to the apposition of the septal leaflet to the posterior ventricular wall. Other reasons why we cannot subscribe to the Sée and Harken theory have been discussed in previous communications.[7, 12]

The regurgitation produced by a preponderant damage of the posterolateral leaflet is by no means of less danger to the patient, as would be the case if the above assumptions were entirely correct. The Mayo Clinic group has recently reported two peculiar cases of mitral insufficiency.[13] The first patient, a 52-year-old man, developed mitral incompetence as the result of rupture of the chordae tendineae of the ventricular leaflet and died in intractable cardiac failure one year after the episode. In the second patient, a 43-year-old rheumatic woman, a subacute bacterial endocarditis had healed producing a fusion of the posterolateral leaflet with the ventricular wall. Thirteen months later the patient died in intractable cardiac failure. These two fatal cases of mitral incompetence due to isolated involvement of the ventricular cusp indicated, by the rapidly declining clinical course, the great importance of this leaflet in the mechanism of valve closure. It should be borne in mind that Adam's patient, with a hole in the aortic cusp from a bullet, began to feel ill effects four years after the attempted suicide and lived six more years.

Junctional Tissue and Accessory Cusps.—The two major cusps are joined to each other at either extremity by a cuff of valvular tissue which we may call junctional tissue. This junctional tissue often becomes differentiated into one or two minor cusps. These are termed anterior and posterior accessory leaflets and separate the aortic from the ventricular leaflet at either extremity (Figs. 2, and 4, *A* and *B*).

Considerable controversy exists regarding the incidence of occurrence of these additional cusps as well as upon their importance from the physiologic and pathologic standpoint.

Many textbooks of anatomy claim that the two major leaflets are "ordinarily" (Testut[14]), "usually" (Quain,[15] Gray,[16] Chiarugi[17]), "some times" (Bertelli,[18] Poirier-Charpy[19]), separated at each of their extremities by the presence of small projections of valvular tissue. Many others say that the major leaflets are continuous with each other by means of a short cuff of tissue (Morris,[20] Brazier,[21] Sappey,[22] Gegenbaur,[23] Valenti[24]). However, we could not find any details as to the frequency of occurrence, importance, and size of the additional cusps or junctional tissue.

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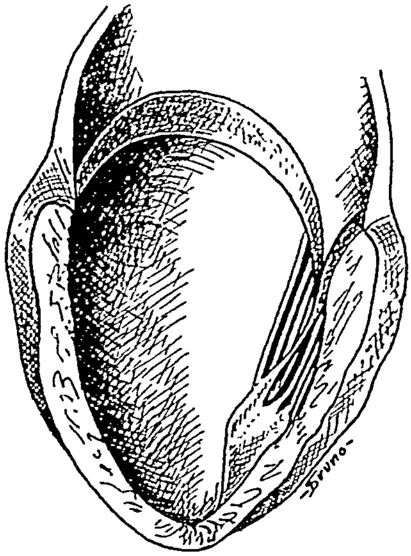

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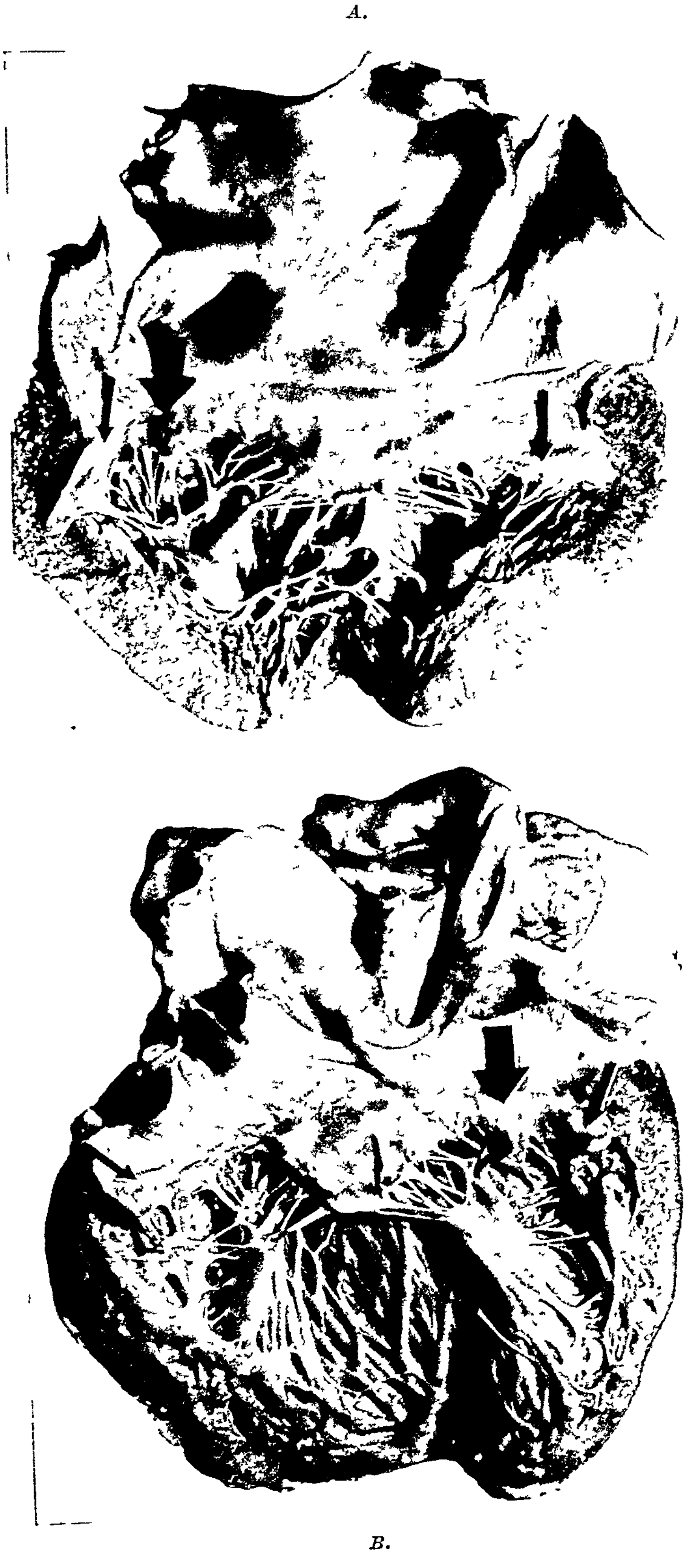


Fig. 4 —*A*, Human mitral valve with anterior accessory leaflet. *B*, Human mitral valve with posterior accessory leaflet. These minor cusps are indicated by two big arrows. The small arrows point to the ventricular leaflet. (Institute of Pathologic Anatomy, University of Bari Medical School, Italy, Autopsy Nos. 2595 and 2607.)

Recently in the wake of interest aroused by mitral valve surgery, two groups of workers have investigated the anatomy of the normal mitral valve. As to the occurrence of accessory cusps, the figures given by these authors are well apart from each other.

Harken and his colleagues[2,5] state that in 75 per cent of 35 normal hearts studied, the mitral valve pattern was that of "four triangular leaflets arranged circumferentially." That is, the presence of two major leaflets plus two additional triangular projections which they called "anterior and posterior commissural leaflets." In the remaining 25 per cent, variation was principally in the size and shape of the ventricular leaflet in relation to the two commissural leaflets. In opposite views, Rusted and associates,[3] on the basis of observations made on 100 normal hearts, state that "in 5 of the 100 hearts there were very tiny projections which conceivably could be called 'accessory cusps' at one or both commissural sites."

With the hope of presenting a contribution to the solution of this controversial matter, we studied the rate of occurrence of these additional cusps and their importance in the function of the valve as well as the importance of the junctional tissue in the cases without additional cusps.

Table III contains the data collected from our investigation. In 41 normal mitral valves (39.0 per cent), there were no accessory cusps and at their bases the major leaflets *were continuous with each other by means of the so called* junctional tissue. Of the remaining 64 mitral valves with accessory leaflets, 22 had both anterior and posterior accessory, 30 had only the anterior and 12 only posterior. Rusted and associates state that "frequently the posterior cusp is notched, and it is possible that other observers have considered one of these subdivisions of the posterior cusp as separating the main portion of the anterior and posterior cusps." This is a possibility to be seriously considered. In our experience, however, the posterior leaflet was seen to be notched in such a way as to be the source of confusion only three times. In these cases, the location of the false accessory leaflet left no doubt as to its relationship to the posterior leaflet. In other cases, the indentations on the free edge of the ventricular leaflet were not deep enough to produce the impression of an additional cusp.

TABLE III. THE FREQUENCY OF ACCESSORY LEAFLETS IN NORMAL MITRAL VALVE (105 HEARTS)

	CASES	PER CENT
Mitral valve with anterior and posterior accessory leaflets	22	20.9
Mitral valve with anterior accessory leaflet	30	28.6
Mitral valve with posterior accessory leaflet	12	11.5
Mitral valve without accessory leaflets	41	39.0
Total	105	100.0

Fig. 5 shows three normal mitral valves carefully removed from their attachments to the atrioventricular annulus and to the chordae tendineae. The heart has been opened from the posterior aspect of the left ventricle and therefore the ventricular leaflet has been divided in two portions located at either extremity of the valve. The drawing was obtained by passing a tracer around the boundary line of the valvular tissue placed over a piece of cardboard. The greatest care was taken in preserving the same dimensions found on the valve in the opened heart. The valve *A* has four cusps, the valve *B* has three cusps, the valve *C* has only two major leaflets. From the drawing it can be concluded that the posterior junctional zone is considerably smaller than the anterior, whether or not it is differentiated into an accessory cusp.

From Table III it can be seen that an accessory leaflet was at the anterior junction zone in 50 per cent or 52 cases, while in the posterior half of the valve an additional cusp was found in 32 per cent or 34 cases. This would indicate that an accessory leaflet is absent in more than two-thirds of individuals at the posterior junctional zone. The data obtained by planimetric integration of the anterior and posterior accessory cusps (Table II) show that the posterior minor cusp surface area is consistently smaller than that of the corresponding anterior minor cusp area. When the latter is absent, the posterior minor cusp is even smaller than the anterior junctional tissue. In addition, the linear measurements listed in Table I reveal that the height and the breadth of the minor anterior leaflet are always greater than those of the posterior minor cusp. The same findings are obtained by investigating the surface area of the junctional tissue. Here again, the posterior junctional tissue was found to be consistently smaller than the corresponding anterior (Table II). From these premises it would seem logical to conclude that the posterior junctional zone is the weakest point of the mitral valve from the functional standpoint.

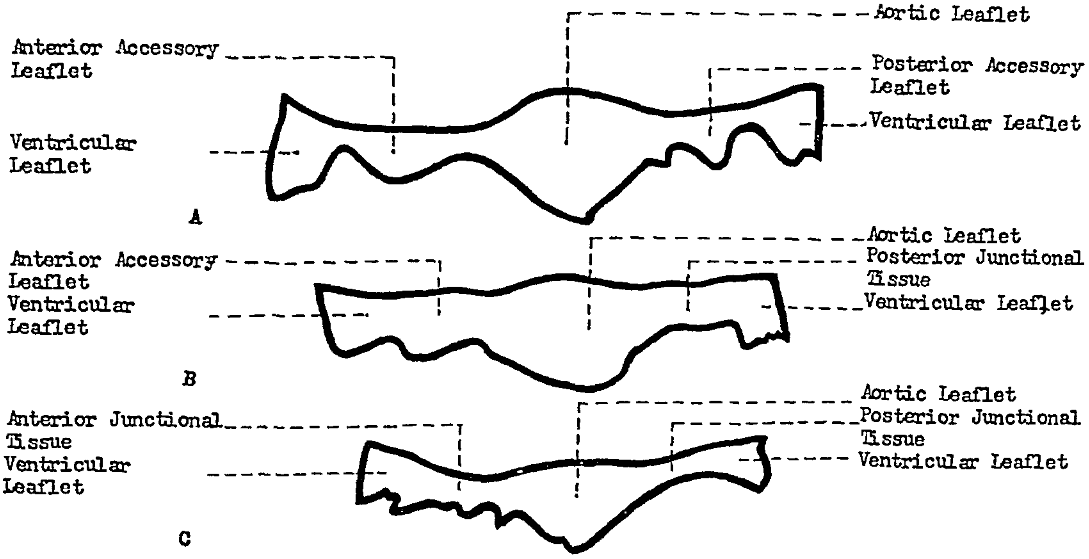
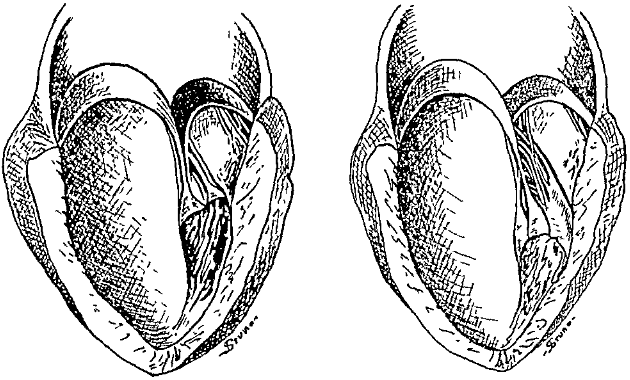

Aortic Leaflet
Anterior Accessory Leaflet
Posterior Accessory Leaflet
Ventricular Leaflet
Ventricular Leaflet
A
Aortic Leaflet
Anterior Accessory Leaflet
Posterior Junctional Tissue
Ventricular Leaflet
Ventricular Leaflet
B
Aortic Leaflet
Anterior Junctional Tissue
Posterior Junctional Tissue
Ventricular Leaflet
Ventricular Leaflet
C

Fig. 5.—Mitral tissue of three normal mitral valves. *A*, Mitral valve with four leaflets. *B*, Mitral valve with two major leaflets and the anterior accessory cusp. *C*, Mitral valve with two major leaflets and no accessory cusps. The posterior junctional tissue is considerably smaller than the anterior, whether or not it is differentiated in an accessory cusp. (From Chiechi and Bailey: La Valvola Mitrale, Courtesy "Il Pensiero Scientifico, Editore," Rome, Italy, 1954.)

This can easily be proved in a normally beating human heart during a ventricular contraction. By inserting the index finger at the level of the posterior extremity of the line of closure a powerful regurgitant jet is promptly obtained. The identical maneuver anteriorly does not produce the same prompt result. The wealth of valvular tissue permits a greater degree of mutual surface contact of the leaflets at the anterior extremity of the valve orifice (Fig. 6, *A* and *B*). The valve closure is more solid and valvular incompetence is less readily produced. On the contrary, the relative shortage of the valvular tissue at the posterior junctional zone brings about a lesser degree of surface contact of the leaflets. The valve closure, competent under normal conditions, is made promptly incompetent by the simple maneuver we have described.

This peculiar anatomic situation may have a bearing upon the observed preponderance of the localization of rheumatic valvular incompetence at the posterior portion of the mitral orifice. The healing fibrosis, consequent to a rheumatic valvulitis, could easily destroy the few millimeters of depth of the posterior junctional tissue. This would be more so if the rheumatic process was predominantly in this region. The production of a commissure would not take place, because the intervening defect would make impossible the fusion by adhesions of the opposite leaflets at this level.[7, 12]



A. *B.*

Fig. 6.—*A*, Section of normal mitral valve through the anterior papillary muscle during ventricular systole. There is a great degree of mutual surface contact near the anterior extremity of the line of closure. *B*, Same section through the posterior papillary muscle showing a lesser degree of surface contact near the posterior extremity of the line of closure. (From Chiechi and Bailey: La Valvola Mitrale, Courtesy "Il Pensiero Scientifico, Editore," Rome, Italy, 1954.)

The function fulfilled by the junctional tissue and/or the minor accessory cusps in the normal mitral valve is that of supplying valvular tissue at either extremity of the major valve leaflets. *The peculiar configuration of the major* cusps with their sloping side requires the presence of additional valve tissue in order to attain a taut valvular closure at each extremity of the line of closure. It should be borne in mind that the closure of the normal mitral orifice is brought about not merely by an edge-to-edge contact of the valve cusps, but by a considerable degree of mutual contact along strips of the atrial surface of the leaflets. The latter process would not be possible without the additional valvular tissue of the junctional zone. This can easily be proved by a modified Luciani test: If in a normal heart, the left atrial wall is removed, th

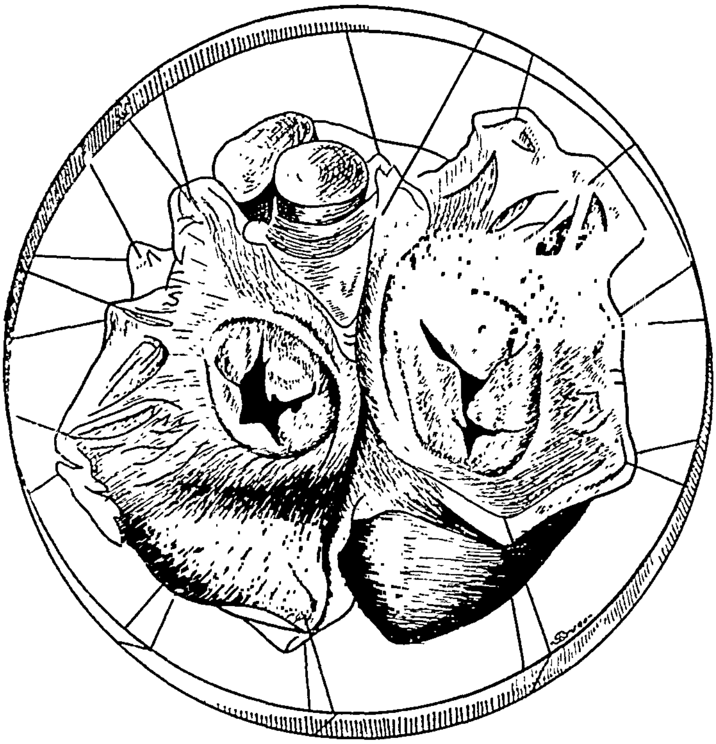


Fig. 7.—The mitral leaflets are floating on the water surface. The ventricular cavity is almost filled with water. The divided atrial walls are fixed with sutures to a circular support. The aorta and pulmonary artery openings are obstructed with corks.

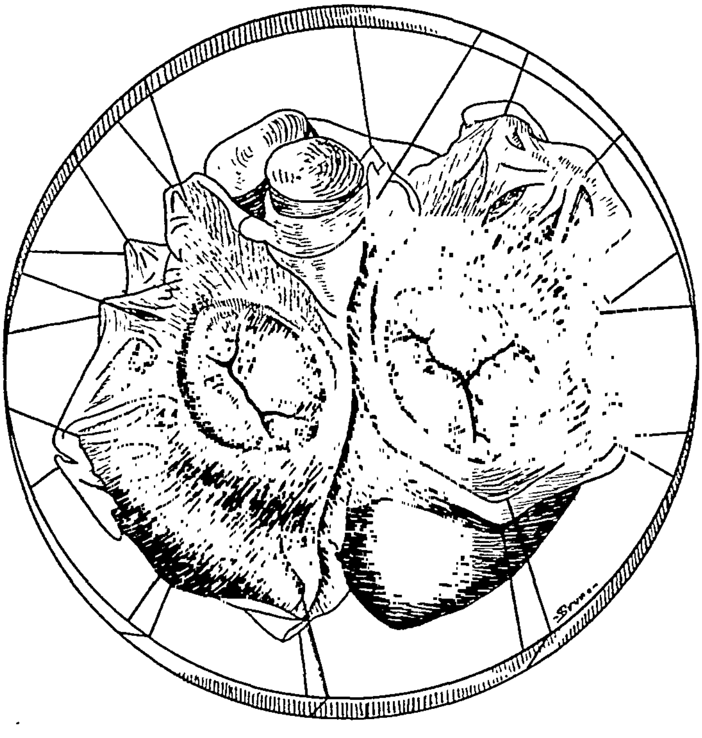


Fig. 8.—Complete closure of the mitral valve when the ventricular cavity is filled with a forceful jet of water (Luciani test). The specimen used in this experiment had a mitral valve with four cusps.

obstructed with a big cork and the ventricular cavity is almost filled with water, the valvular cusps are seen to float on the surface in the position of incomplete closure (Fig. 7). A sudden and forceful jet of a few cubic centimeters of water in the direction of the longitudinal axis of the ventricle brings about for a moment the complete closure of the valve orifice (Luciani test)[26] (Fig. 8). When *the junctional zones are removed, even though the remaining* valve cusps float on the surface, the further forceful introduction of water is almost without any effect (Fig. 9). The removal of the junctional zones makes impossible the

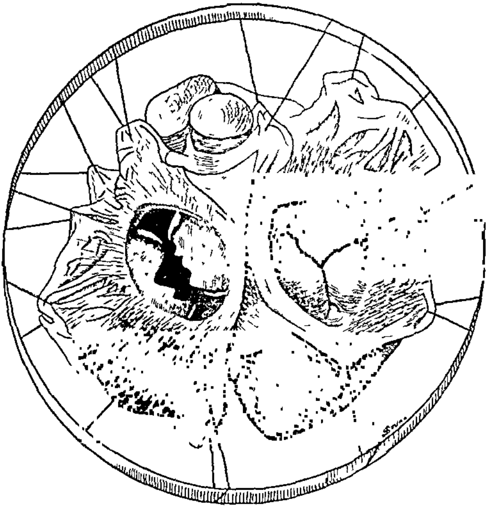


Fig. 9.—The accessory cusps have been removed. The water pours out of the ventricular cavity through the defects and the major valve leaflets never come into contact with each other.

formation of the centrifugal eddy currents to which the temporary valve closure is due. Consequently, the water pours out of the cavity through the defect at both extremities of the line of closure. The procedure is likewise unsuccessful when the junctional zone of a dead heart is cut only radially, from its free edge to the valve ring. The two divided portions never come into contact thus permitting the escape of water through the dividing lines. The last procedure can be easily performed on the living heart of a dog. Here again, the result is valvular incompetence of a moderate degree. One of us (M. A. C.) has repeatedly created valvular incompetence in the experimental animal using the original Bailey hook knife. The degree of this incompetence has unfortunately not been recorded.

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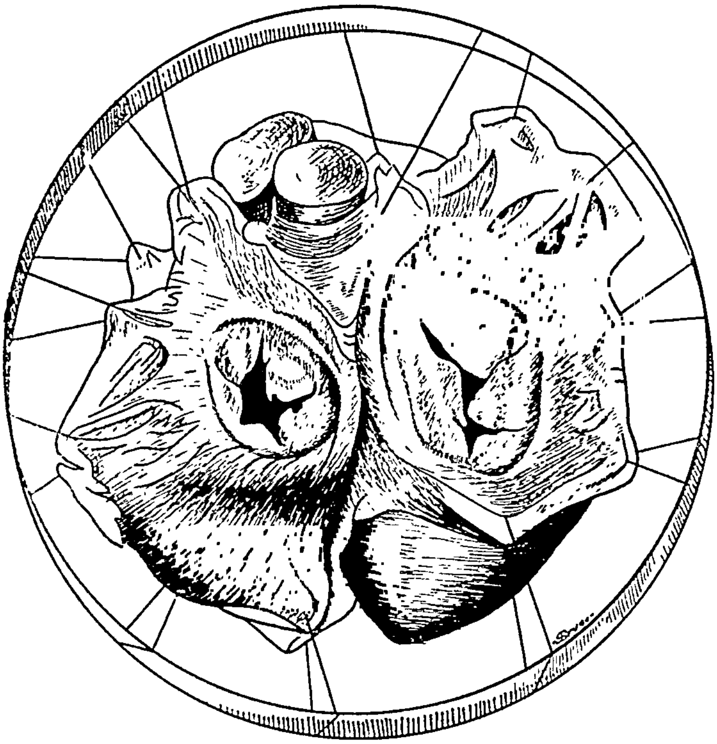

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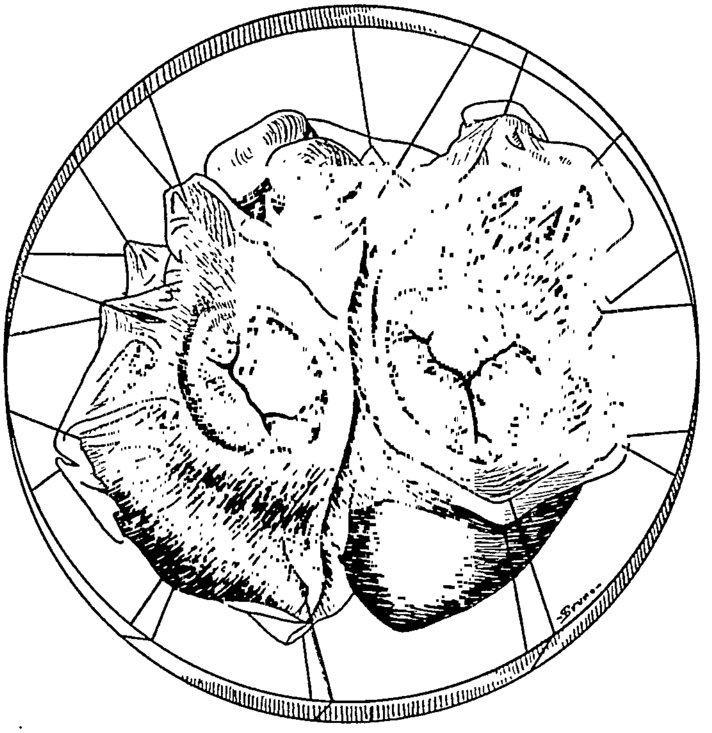

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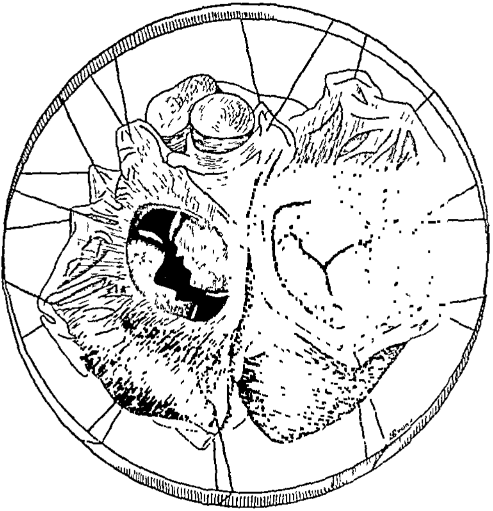

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Because of the importance of the junctional tissue in the mechanism of valve closure as just described, we are of the opinion that the commissurotomy, whether by separating the commissures with the finger or by cutting them apart with a knife, should never reach the mitral ring. The opening obtained by arresting the procedure a few millimeters from the mitral annulus is usually satisfactory. By enlarging it up to the atrioventricular ring, the patient is exposed to the danger of valvular incompetence which is generally serious in a heart with mitral stenosis and a limited myocardial reserve. We have seen the production of a regurgitant jet many times following the last stroke of the finger or the knife, especially while working on the posteromedial commissure.

The last discussion brings up the still unsolved matter of the commissures in a normal heart. We believe that in the normal mitral valve there are no commissures. The textbooks of anatomy and the current medical knowledge are consistent in teaching that the mitral valve is a structure made up by two leaflets and two commissures at either extremity. Recently Rusted and coworkers[3] insisted upon the matter and, in agreement with the classical teaching, have designated as the commissures of a normal mitral valve, the normally existing junctional tissue.

Lending support to this view, it would be interesting to know where the commissures should be located in those cases with one or both accessory cusps and no junctional tissue. Moreover, close observation of a normal mitral valve, from the atrial and ventricular aspect, reveals a continuous veil of valvular tissue inserting around the circumference of the mitral orifice without any trace of commissure in the Latin sense of this word. The Latin "commissura" means joint or juncture. A joint requires connective tissue in various degrees of organization. In the case of a normal mitral valve, the junctional tissue is anatomically and histologically not different from the rest of the valvular tissue. On the other hand, when a rheumatic infection has taken place in the valve, the fibrous tissue reaction leads to the fusion of the opposite cusps and produces a commissure. For these reasons, it is difficult for us to justify the validity of the classical view. Consequently, the commissure ought to be considered as a phenomenon, uniquely and exquisitely pathologic.

Chordae Tendineae.—The atrial aspect of the normal mitral valve is a smooth, glistening surface which makes up the floor of the left atrium during ventricle systole. The ventricular aspect instead is somewhat irregular, because of the insertion of the chordae tendineae.

The chordae tendineae are tendinous, stringlike structures connecting the valvular tissue to the papillary muscles or to the ventricular myocardium. The former, distinct in chordae of first and second order, according to the accepted terminology, could be considered the tendons of insertion of the corresponding papillary muscle; the latter, chordae of third order, are shorter bands that directly connect the valve, mostly the ventricular cusp, to the ventricular wall.

From each papillary muscle the chordae tendineae spread out like the sticks of a fan to the corresponding halves of both major valve leaflets and to the junctional tissue and/or to the accessory leaflets in between. Taken together, the valve and the two fanlike arrangements of chordae could be likened to a parachute. Only occasionally has there been found a very thick chorda connecting the anterolateral muscle directly with the mitral ring.

The chordal attachment does not include the atrial aspect of the leaflets. The central portion of both major valve leaflets and the ventricular aspect of the aortic leaflet are likewise devoid of chordae.

The chordae tendineae of first order are inserted on the free edge of the leaflets. They are tenuous, threadlike structures, usually smaller and thinner and more numerous than the chordae of second order. They are frequently branched and connected with adjacent chordae by delicate anastomosis. Often they insert on the free margin of the cusp by a process of dichotomy and the two resulting branches are held together by a very thin membranous expansion of valvular tissue.

The function of these marginal chordae is that of preventing the eversion of the free margin of the leaflet into the cavity of the left atrium during ventricular systole.

The chordae tendineae of second order are thicker and are inserted on the ventricular aspect of the cusp at a short distance 0.3 to 0.6 cm. from the free edge. They end at almost regular intervals in endocardial folds but often run through the substance of the valve up to the atrioventricular ring as mentioned earlier.

In 71 per cent of the normal hearts studied in this series, it has been possible to observe chordae tendineae of second order, slightly thicker than the other, arising from the very top of the papillary muscles and inserting at each extremity of the central portion of the aortic cusp. An analogous pattern is lacking on the ventricular leaflet.

It is usually taught that these chordae going from the papillary muscles to the central portion of the anteromedial leaflet are very important in maintaining the competency of the mitral valve. Brock has even offered a pathogenetic theory of mitral stenosis, very debatable indeed,[7] based on the importance of the primary attachment of chordae tendineae that he calls "critical areas of tendon insertion."[10]

It seems to us that the functional meaning of those chordae inserting at the central portion of the aortic leaflet is that of holding steadily and firmly the cusp during ventricular systole. In addition to that, they have the task of limiting the amount of ballooning of the leaflet toward the atrium. The enormous intraventricular systolic pressures, which tend to invert the cusp into the atrium, are efficiently offset by these tendons with great tensile strength. It is well to remember that the aortic leaflet is the largest mitral cusp and yet, it has no chordae tendineae of third order. The function of these last fibrous bands seems to be essentially that of anchoring the cusp and preventing its inversion into the atrium during the ventricular contraction. It would be difficult to explain differently the immediate purpose of these short, broad tendons, stretching across the perivalvular space and joining directly the valvular tissue with the ventricular wall.

The insertion of the chordae tendineae of third order concerns mostly the ventricular leaflet, because the junctional tissue and the accessory leaflets are directly connected to the ventricular wall only rarely. This, we believe, should be the reason why the aortic leaflet has thicker chordae tendineae [illegible] the top of the papillary muscles to its central portion, while th [illegible] cusp does not. The amount of pressure which the aortic leaflet must sustain during ventricular contraction is greater than that of the ventricular cusp. In spite of the fact that the pressure is evenly divided on every square unit of the ventricular cavity, the aortic cusp, being larger than the ventricular, has to support a greater proportion of strain.

Papillary Muscles.—The papillary muscles are the last components of the mitral valve apparatus. They belong to the system of columnae carneae of the heart and are the only cases of columnae carneae of first order. They originate from the ventricular wall and lie between the major mitral leaflets directly inferior to the valve junctional zone. Their location is anterolateral and posteromedial in the inflow tract of the left ventricular cavity. At their base the muscles are joined by columnae carneae of second and third order whose contraction brings the two muscles close together in systole.

Each chordal fan originates mainly from the apex of each papillary muscle and extends to the corresponding halves of the mitral major leaflets.

The papillary muscles may be single, double, triple, or even formed by more than three muscles. The results of our investigation on this anatomic aspect of the papillary muscles are not too different from those of Rusted and colleagues (Table IV). The muscle with an apex, only slightly or not at all grooved, was considered single. Two muscles or a muscle with two heads was considered double. Three muscles or a trifid muscle was considered triple.

TABLE IV. TYPES OF PAPILLARY MUSCLES IN 105 NORMAL HEARTS

TYPES OF PAPILLARY MUSCLES	ANTEROLATERAL MUSCLES		POSTEROMEDIAL MUSCLES	
	CASES	PER CENT	CASES	PER CENT
Single	87	82.8	31	29.5
Double	15	14.3	57	54.3
Triple	3	2.9	12	11.4
More than three	-	-	5	4.8

More than four-fifths of the anterolateral papillary muscles proved to be single, while more than two-thirds of the posteromedial muscles were multiple. As pointed out by Rusted the most frequent combination was that of a single anterolateral muscle with a double or triple posteromedial papillary muscle, occurring in our series in almost two-thirds of the cases. Occasionally, the accessory cusps have their chordal attachments on an independent small muscle head at the anterolateral and posteromedial sites.

Another aspect of the anatomy of papillary muscles which has been investigated is that of the possibility of their becoming interlocked into one another during ventricular systole. The old anatomists thought that in systole the usually single and round-shaped anterolateral muscle could approximate and occupy the hollow formed by the usually multiple posteromedial muscle. It was entertained also that the posteromedial muscle was placed in such a way on the posteromedial wall of the heart as to offer a hollow surface to the anterolateral muscle. This nice and elegant view, on which Lutembacher has also written,[27] would not be given support by our work. Table V lists the data on the inner surface of the papillary muscles; that is, the surface facing the

Table V. Types of Inner Surface of Papillary Muscles in 105 Normal Hearts

TYPES OF PAPILLARY MUSCLES	ANTEROLATERAL MUSCLES				POSTEROMEDIAL MUSCLES			
	CONVEX		CONCAVE		CONVEX		CONCAVE	
	CASES	PER CENT	CASES	PER CENT	CASES	PER CENT	CASES	PER CENT
Single	84	80.0	3	2.8	31	29.5	–	–
Double	8	7.7	7	6.8	15	14.3	41	39.0
Triple	1	0.9	2	1.8	4	3.8	14	13.4

long axis of the left ventricle. It can be seen that in 50 of 105 normal hearts, the inner surface of the posteromedial muscle was convex instead of being concave as would have been the case if the above-mentioned view was entirely correct. It can be reasonably expected, however, that the muscles come into mutual contact in systole, even though their arrangement does not appear to be set for an interlocking contact in the sense that the early anatomist described.

CLOSURE OF THE NORMAL MITRAL VALVE

Considering the valvular tissue surface area as a whole in relation to the mitral orifice area, it is of interest to observe that the former, by and large, exceeds the latter. The relationship between the two areas is, according to our investigation, very close to 2 to 1 in many cases. In a few cases the relation is 1.5 to 2, but never is it less than that. In other words, there is always an excess of valvular tissue in relation to the area of the orifice. The difference becomes even greater in systole because of the sphincterlike action of the atrioventricular ring which further reduces the orifice's area. The closure of the *mitral aperture is therefore the tautest possible, because the valve leaflets not* only meet at their free margins, but they come into very extensive mutual contact along most of their atrial surface.

We can visualize well the mechanism of closure of the normal mitral orifice by the valve leaflets as a process involving three succeeding phases. At first, the leaflets meet edge to edge; then, under the progressive contraction of the myocardial fibers and the increased intraventricular pressure, the chordae tendineae are pulled while the cusps come into surface contact, ballooning toward the atrial cavity; in the last phase, the mutual surface contact between the leaflets becomes more and more extensive, so that when the blood is forced out into the arota by the contraction of the deep circular muscles of the heart, the leaflets are disposed against each other in an almost vertical position (Luciani).

The mechanism of valve closure, far from being so simple, is the result of complex interaction of the various components of the valve apparatus and the ventricular and atrial myocardium.

Hydrodynamic pressure changes following the rapid inflow and atrial systole would be entirely responsible for the first phase according to some authors (Henderson and Johnson,[28] Little[29, 30]). A modern version of this view is that bringing into play the Venturi effect at the time of rapid inflow when the valve is in the condition of incomplete closure (Rodbard[31]). Still some others believe that the production of turbulent flow and the consequent formation of eddies behind the cusps at the end of the atrial [illegible] drive the mitral leaflets one against the other (Luciani). There are investigators, however, who are of the opinion that the valve closure by atrial mechanism is incomplete and temporary (Dean,[32] Wiggers,[33] Smith and co-workers[2]).

The second phase of the mitral valve closure is simultaneous with the ventricular systole. The contraction of the superficial layers of myocardial fibers together with that of papillary muscles causes various events to take place. The atrioventricular ring reduces somewhat its circumference, the intraventricular pressure rises rapidly, causing a forceful pull of the chordae tendineae and the bulging of the valvular tissue toward the atrium. The mitral leaflets from the marginal contact of the first phase progress to a surface contact over a considerable portion of their atrial aspect at the end of this phase.

When the intraventricular pressure exceeds the aortic pressure at the onset of the maximum ejection period, the valve closure is made perfectly hermetic. The contraction of the deep sinospiral muscle, embracing both ventricles at their base, and that of the deep bulbospiral muscle, encircling the mitral and the aortic orifice,[34] further decrease the circumference of the atrioventricular annulus. While the blood is being expelled into the aorta by the contraction of these muscles, the mitral leaflets come into mutual surface contact over almost all of their atrial aspect and may even reach a vertical position. The mitral orifice is brought down to a fraction of its original area by the constricting action of the deep circular muscles and the redundant valvular tissue is pulled down vertically. This goes on for the maximum and reduced ejection periods up to the onset of diastole. With the opening of the mitral valve, the rapid inflow of blood sets the leaflets in a position of incomplete closure and the cycle starts all over again.

SUMMARY AND CONCLUSIONS

The purpose of our investigation was to study some of the features of the normal mitral valve, which have received only scant attention in the voluminous literature connected with mitral valve disease. It was also our concern to assess the importance of these structures in the mechanism of mitral valve closure. The mitral valve apparatus was described in toto in order to present a clear outline of its functional anatomy.

We found some widely accepted notions about functional anatomy of the mitral valve, which have not received support from our research. No anatomic or functional basis was found for the alleged baffling action of the aortic cusp. Neither was it possible to accept the theory that the mitral valve is closed by the sole action of the aortic leaflet, while the posterior wall of the heart buttresses the posteromedial leaflet.

We believe that the importance of the ventricular leaflet in the mechanism of the valve closure is strictly proportional to the extent of its surface area as compared with that of the other portions of the mitral veil. If the ventricular cusp is to serve no useful purpose in the mechanism of valve closure, there would be no reason for it to be there. Furthermore, the notion that valvular incompetence with the opening at the outflow tract of the left ventricle is more serious than valvular incompetence due to isolated involvement of the ventricular leaflet, remains open to question. The seriousness of a regurgitant lesion is governed mainly by the sectional area of the defect and much less by its spatial orientation. The 2 cases from the Mayo Clinic, mentioned earlier, show convincingly the extreme gravity of a regurgitant lesion of the ventricular leaflet. It is true that compensatory mechanisms may occur posteriorly, but these do not appear to be related to the posterior ventricular wall.

A constituent of the mitral valve which needs to be better understood is the junctional tissue. It is frequently designated as a valvular commissure, but we have described the reasons for not accepting the term "commissure" when speaking of the junctional tissue in a normal mitral valve.

In the diseased mitral valve, the commissures have the same location as the junctional zones in a normal mitral valve. However, these junctional structures make up only the deepest part of the commissures, i.e., the part closest to the mitral ring.

Undoubtedly, the junctional zones are of considerable importance from the anatomic as well as the physiologic standpoint. As recently as 1924, Coombs[35] theorized that the progressive shrinkage of the junctional tissue from rheumatic involvement was responsible for the production of mitral stenosis.

Our study of the junctional zone in the normal mitral valve revealed that (1) the junctional tissue more often than not is differentiated in one or two minor cusps, succeeding in alternation to the major leaflets, (2) an accessory cusp is lacking more often posteriorly than anteriorly, (3) the amount of valvular tissue is smaller posteriorly than anteriorly, and (4) the junctional zone is essential to good function of the valve because its division, in the experimental animal, causes a moderate degree of valvular incompetence.

As a corollary to these findings, it follows that the posterior portion of the mitral valve is the least gifted with valvular tissue and therefore the weakest part of the valve. We believe that the observed preponderance of valvular incompetence at the region of the posterior commissure is probably due to this shortage of valvular tissue in this region. The posterior junctional tissue could be destroyed by a rheumatic process more easily than the anterior which is richer in valvular tissue. We are of the opinion that no commissurotomy should ever reach the mitral ring, because of the importance of maintaining a cuff of valvular tissue to insure closure of the orifice. By splitting the valvular tissue up to the annulus, a fatal regurgitation might be produced. It is well known that a posterior commissurotomy more often is followed by a surgically produced valvular incompetence than is an anterior separation. If the operation has been adequate, that is, if the division has been in the line of the commissure, the production of incompetence could be explained only by the fact that the junctional tissue has been divided along with the commissure. This is much more easily done posteriorly because the posterior commissure is usually less deep than the anterior and the atrioventricular annulus is reached promptly by a stroke of the finger or of the knife.

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PROLONGATION OF SAFE PERIOD OF VENOUS INFLOW OCCLUSION IN HYPOTHERMIC STATE BY CORONARY AND CAROTID ARTERY PERFUSION WITH OXYGENATED BLOOD

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HELPFUL as hypothermia has been as an aid for open cardiac surgery, it has two principal disadvantages The first is concerned with increased myocardial irritability and particularly with the hazard of ventricular fibrillation In other studies,[1-6] we have demonstrated that this danger can be minimized by anesthetic infiltration of the superior vena caval right atrial junction, by operative sympathetic denervation of the heart or sympathetic blockade with drugs and, as Montgomery and associates have also demonstrated, by stimulation of the right vagus nerve Other workers have confirmed the effectiveness of anesthetic block of the vena caval right atrial junction[8-10] The other disadvantage relates to the relatively brief period of venous inflow occlusion compatible with recovery without neurologic damage This study is concerned with this problem It deals with the effect of perfusing, with oxygenated blood, the coronary and carotid arteries

MATERIAL AND METHODS

Healthy mongrel dogs weighing between 6 and 13 Kg were used They were anesthetized by the intravenous administration of from 2 to 4 c c of 10 per cent thiopental sodium, intubated and hyperventilated with 100 per cent oxygen by means of an intermittent insufflation apparatus producing between 35 and 45 respirations per minute The animals were cooled to a temperature of 30° C by immersion in a bath of water and crushed ice If shivering occurred, it was controlled by administering, temporarily, a mixture of ether and oxygen The animals were then removed from the ice bath and by the time the chest was entered the temperature had fallen an additional 3° to 5° C

The blood for infusion was obtained by bleeding hyperoxygenated normal dogs from the femoral artery The blood was collected in vacuum bottles containing either 20 mg of heparin or a small amount of sodium citrate, citric acid, and dextrose The blood was withdrawn just before each experiment and was stored, temporarily, in a refrigerator kept at 4° C, for twenty or thirty minutes The blood was grossly well oxygenated In some of the experiments, this arterialized blood was saturated further by bubbling through it a jet of 100 per cent oxygen

In each case, the right atrial superior vena caval junction was infiltrated with 1 per cent procaine solution until satisfactory slowing of the heart occurred and the charac

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teristic disappearance of, or reduction in voltage of, the electrocardiographic P wave. The injection was repeated every fifteen minutes when heparinized blood was used. It was repeated just prior to release of vena caval clamps when citrated blood was employed.

The venae cavae were occluded with Pott's clamps and one minute later the aorta was cross-clamped distal to the point of entry of the perfusion catheter. Immediately after the perfusion was begun, a 4 to 5 cm. right ventriculotomy incision was made. The animal was placed in Trendelenburg position. The right ventricle was kept empty of blood by aspiration. From twenty to thirty minutes later, the ventriculotomy was repaired with a continuous suture of silk. The superior vena caval clamp was then released and two or three minutes later, the inferior vena caval clamp.

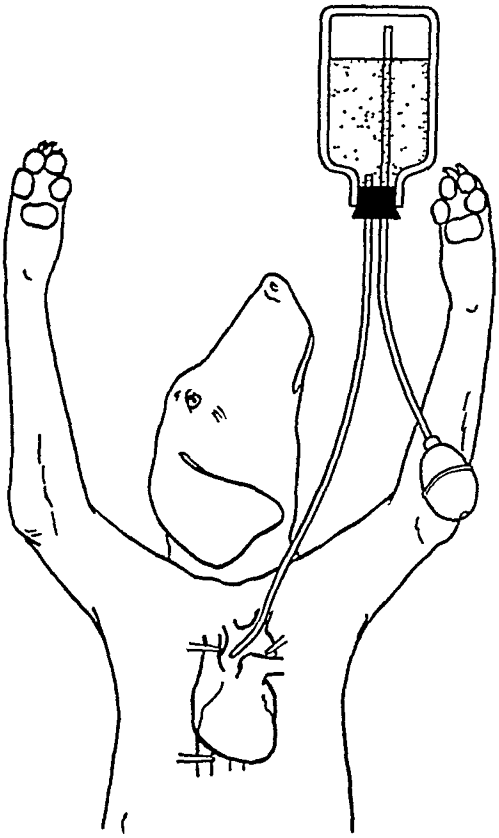

Fig. 1.—Drawing illustrating type of perfusion. Oxygenated blood is delivered from a transfusion bottle suspended over heart, the rate of flow being regulated by manometrically controlled pressure within the flask.

During the perfusion, all blood lost was recovered by aspiration and measured carefully. Intermittently, in cases of carotid and coronary perfusion, blood was allowed to escape through the opened heart while the superior vena caval clamp was momentarily released in order to equalize the amount of blood perfused and that recovered by aspiration.

The oxygenated blood was perfused at a rate of from 25 to 35 c.c. per minute, by gravity flow, using manometrically controlled pressure in the infusion bottle to regulate the speed of administration (Fig. 1). At the completion of the experiment, the perfusion catheter was removed. The stab wound in the aorta was closed with silk sutures, or the left subclavian artery was ligated. The pericardium was approximated loosely. The chest wound was repaired. Catheters were left in the pleural cavity until rewarming had occurred. As soon as the chest wall was repaired, the animal was warmed to a temperature of approximately 36° C. by immersion in a water bath kept at 45° C. The indwelling catheters were then removed after aspiration was carried out. The animal was left in a warm room for the next sixteen to eighteen hours. Two hundred thousand units of penicillin were administered daily for the first three or four days.

In those experiments in which citrated blood was used for perfusion and the heart was in standstill, cardiac massage was instituted after release of the vena caval clamps. Five cubic centimeters of a 20 per cent solution of calcium gluconate was injected into the right ventricle either before or one minute after institution of cardiac massage. When heparinized blood was used and cardiac contractions were maintained, no calcium was administered and massage was not carried out. At the completion of the experiment, protamine was given, 1.5 mg. for each milligram of heparin perfused.

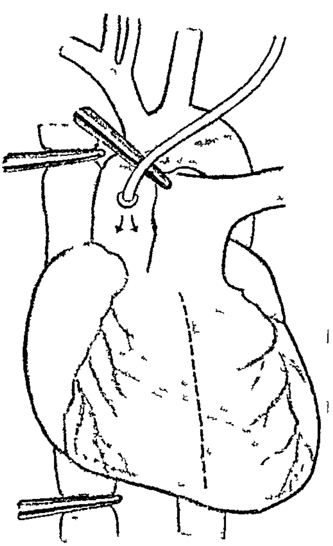

Fig. 2

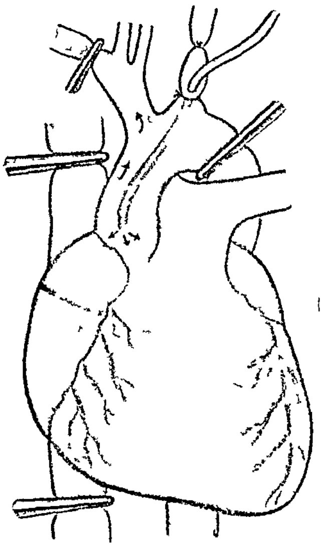

Fig. 3

Fig. 2.—Drawing illustrating perfusion of coronary arteries during venous inflow occlusion.

Fig. 3.—Drawing illustrating perfusion of coronary and carotid arteries during venous inflow occlusion.

Whenever ventricular fibrillation occurred in animals having received either citrated or heparinized blood, vigorous cardiac massage was begun immediately. Unless fibrillation disappeared and sinus rhythm returned, massage was continued until the heart was of good color and the fibrillation strong. In almost all cases, 1 c.c. of 1 to 10,000 epinephrine solution was administered into the right ventricle in order to strengthen the myocardial tone. Three successive electric shocks of 170 volts and 1/10 of a second duration were then applied.

Two groups of experiments were carried out. In the first, the coronary arteries alone were perfused. In these animals, the chest was entered through a right anterolateral fourth intercostal space incision. A small polyethylene catheter with a flange on its end was introduced into the ascending aorta through a small stab wound made in a portion of the aortic wall temporarily excluded from the lumen by application of a curved Pott's ductus clamp. Once the catheter was in place, the clamp was removed and the catheter secured to the aortic wall by two purse-string sutures of No. 5-0 arterial silk. When the perfusion was begun, the aorta was clamped distal to the point of entry of the catheter and proximal to the site of origin of the brachiocephalic trunk (Fig. 2).

In the second group, either a sternal-splitting incision or a bilateral anterior thoracotomy with sternal transection was used. The perfusion catheter was introduced into the ascending aorta through the left subclavian artery which was ligated snugly distal to the site of entry of the catheter. The right subclavian artery was occluded at the point of its origin with a rubber-shod serrefine clamp, and the aorta with a Pott's ductus clamp distal to the origin of the left subclavian artery (Fig. 3).

OBSERVATIONS

In those animals in which heparinized blood was used for perfusion, the heart continued beating with a normal rhythm during the entire period of vena caval occlusion (Fig. 4). With the passage of time, the rate tended to decrease. In general, the heart maintained good color and toward the end of the occlusion

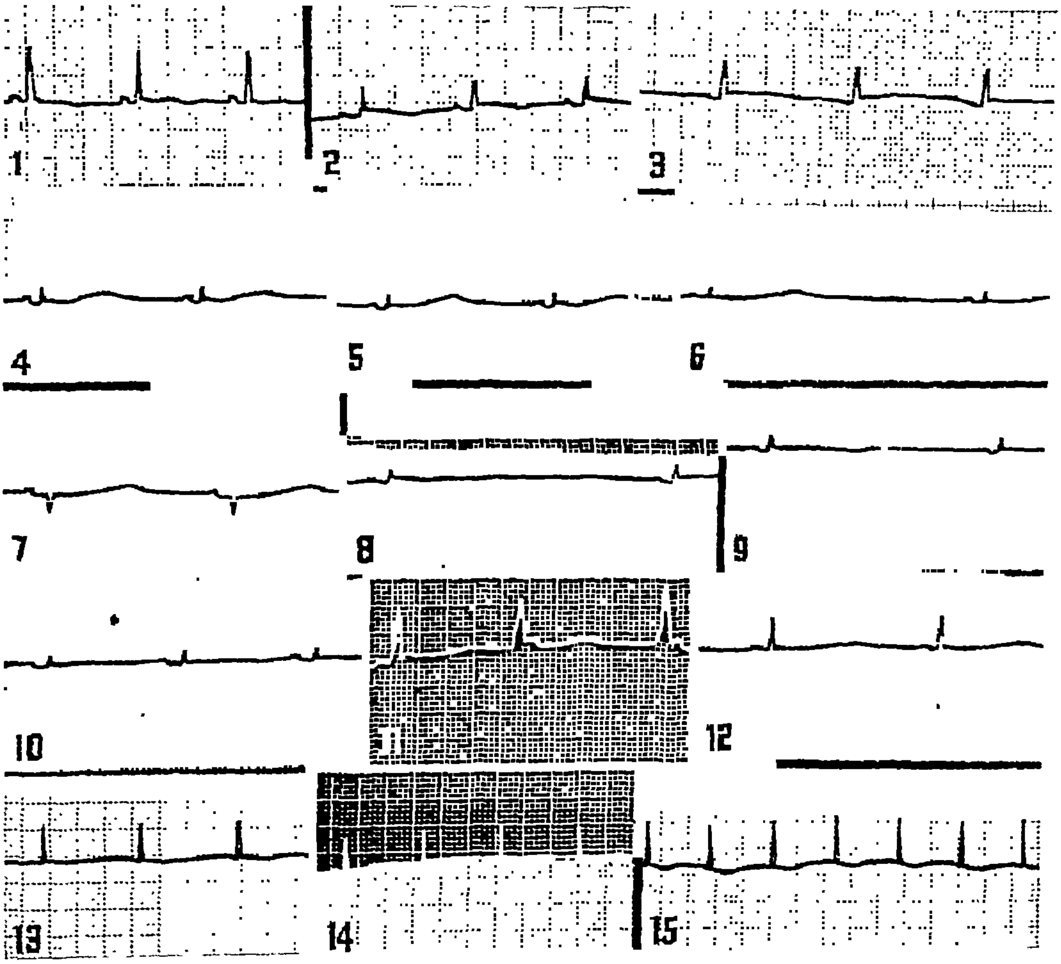

Fig. 4.—(Lead II) Electrocardiographic tracings in case of coronary and carotid artery perfusion with heparinized oxygenated blood. *1*, chest open, 26.5° C. *2*, prior to, and *3*, immediately after procaine infiltration of right atrial-superior vena caval junction. *4*, *5*, and *6*, After 5, 10, and 16 minutes of perfusion. *7*, After second procaine infiltration. *8*, After 29.5 minutes of perfusion. *9*, Following removal of superior vena caval clamp. *10*, Following removal of inferior vena caval clamp. *11*, After closure of pericardium. *12*, Immediately after repair of chest incision. *13*, *14*, and *15*, At body temperatures of 28°, 32°, and 36° C.

time, when the rhythm was slower, the heart was even pinker than it was initially. When ventricular fibrillation occurred, it always developed after termination of the perfusion and release of the vena caval clamps.

When citrated blood was used, the cardiac rate slowed progressively and standstill usually occurred within from five to eight minutes (Fig. 5). In an exceptional animal, a feeble heartbeat continued for a longer period. The heart remained pink and its color became even brighter once standstill took place.

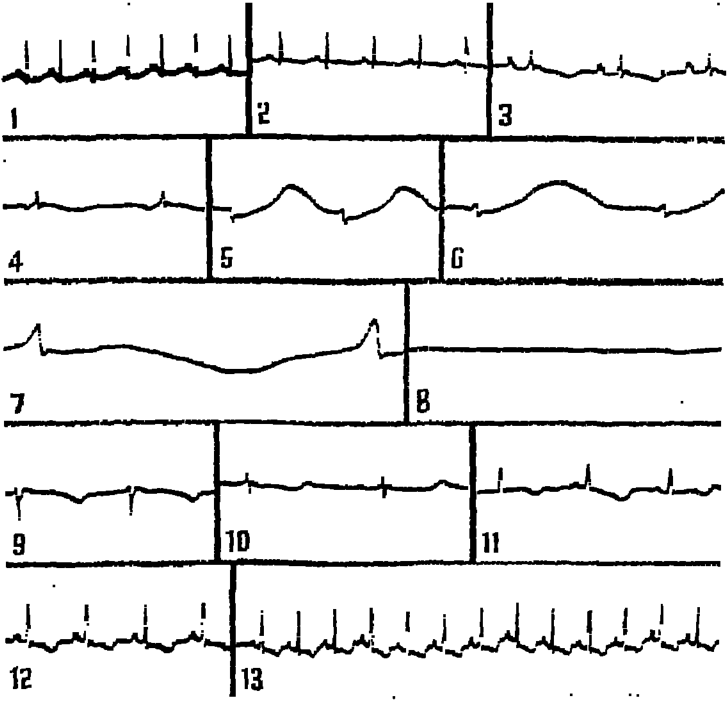

Fig [illegible] (Lead II) in case of coronary and carotid artery perfusion [illegible] 1, 2, and 3, at body temperatures of 37°, [illegible]°, and 26 5° C [illegible] ion of right atrial-superior vena caval junction 5, 6, 7, an [illegible] es of perfusion 9, following cardiac massage and intracardi[illegible] re of the pericardium 11, after repair of chest incision [illegible] of 32° and 36° C.

During this period, also, a striking observation was that the coronary sinus and the Thebesian blood became *more arterial in character* as the perfusion proceeded (Table I). Ventricular fibrillation occurred much more commonly when intracardiac calcium was administered after release of th
and before institution of cardiac massage than when giv
cardiac massage.

TABLE I. OXYGEN SATURATION OF CORONARY SINUS BLOOD DURING CORONARY AND CAROTID ARTERY PERFUSION WITH CITRATED OXYGENATED BLOOD*

NUMBER OF DOG	INTERVAL AFTER BEGINNING OF PERFUSION IN MINUTES		
	2.5	9.5	15
1	56.8	69.9	77.5
2	52.6	64.2	76.8

*The saturation of the perfused blood was 87.8 per cent in Dog 1, 86.5 per cent in Dog 2.

Animals with Coronary Artery Perfusion.—There were 13 animals in this group. In 8, heparinized blood was utilized (Table II). The temperatures of the animals ranged from 24° to 28° C. and the period of venous inflow occlusion from 25 to 28.5 minutes. The blood perfused ranged from 2.1 to 2.8 c.c. per kilogram per minute. In 2 animals, ventricular fibrillation occurred following release of the vena caval clamps and defibrillation was successfully accomplished in both. Two animals, after having made a good immediate recovery, died the day following surgery with hemothorax and hemorrhagic atelectasis. The others made a good recovery and were sacrificed in from 20 to 170 days.

TABLE II. CORONARY PERFUSION WITH HEPARINIZED BLOOD*

DOG NUMBER	WEIGHT OF DOG (KG.)	TEMPERATURE OF DOG (° C.)	TIME CAVAL OCCLUSION (MIN.)	BLOOD PERFUSED (C.C.)	VENTRICULAR FIBRILLATION	FINAL RESULT
2	10	26	25.5	510	No	Stuporous 1 day after surgery, normal afterward; sacrificed 36 days later
168	8	25.5	25	400	No	Same; sacrificed 170 days later
171	8	28	26	600	No	On his feet and well the morning after surgery; dead few hours later from hemothorax
172	6.5	27	26	350	No	Weakness hind legs for 2 days, normal afterward; sacrificed 20 days later
175	7.2	26.5	26	400	No	Stuporous 1 day, normal afterward; sacrificed 160 days later
176	6	26.5	26	360	Yes	Stuporous 1 day, normal afterward; sacrificed 40 days later
185	7.5	26.2	26	400	Yes	Stuporous 1 day; well afterward; sacrificed 155 days later
200	10	25	28.5	600	No	On his feet and well following morning; dead few hours later, hemothorax

*The perfusion rate ranged between 2.1 and 2.8 c.c. per kilogram per minute.

In 5 animals, citrated blood was used (Table III). The temperature ranged between 24° and 26° C. and the period of inflow occlusion from 27.5 to 29.5 minutes. The blood perfused varied from 2 to 2.3 c.c. per kilogram per minute. In 2 animals, intracardiac calcium was administered after release of the vena caval clamps and before cardiac massage was instituted. Ventricular fibrillation promptly developed and in both successful conversion was achieved. In the other 3, intracardiac calcium was administered after a period of cardiac massage and fibrillation did not occur.

TABLE III CORONARY PERFUSION WITH CITRATED BLOOD*

NO NUMBER	WEIGHT OF DOG (KG)	TEMPERATURE OF DOG (° C)	TIME OF CAVAL OCCLUSION (MIN)	BLOOD PERFUSED (C C)	VENTRICULAR FIBRILLATION	FINAL RESULT
207	10.5	25.5	27.5	600	Yes	Weak, stuporous for 3 days, normal afterward, sacrificed 62 days later
225	11.2	26	27.5	600	Yes	In good condition day after surgery, sacrificed 61 days later
227	9.2	24	29.5	560	No	In good condition day after surgery, sacrificed 70 days later
233	9.5	26	28.5	580	No	In good condition day after surgery, sacrificed 72 days later
240	9.5	24.8	28.5	590	No	In good condition day after surgery, sacrificed 114 days later

*The perfusion rate ranged between 2 and 2.3 c.c. per kilogram and per minute

Of the 13 animals in this group, 5 were stuporous for one day and thereafter had no evidence of neurologic damage. One additional animal was weak and stuporous for three days after which he seemed perfectly well. Still another animal showed weakness of the hind legs for two days and was normal afterward. There was no evidence of even transient neurologic damage in the re-

TABLE IV CORONARY AND BRAIN PERFUSION WITH HEPARINIZED BLOOD*

DOG NUMBER	WEIGHT OF DOG (KG)	TEMPERATURE OF DOG (° C)	TIME CAVAL OCCLUSION (MIN)	BLOOD PERFUSED (C C)	VENTRICULAR FIBRILLATION	FINAL RESULT
1	10.2	25.5	29	180	No	Perfectly well day after surgery, no brain damage, sacrificed 120 days later
159	8.5	27.5	29.5	900	No	Same, sacrificed 110 days later
173	7	28	29	650	No	On his feet and well following morning, dead few hours later, hemothorax and intrapulmonary bleeding
179	7.8	28	30	760	No	No brain damage, sacrificed 20 days later
182	6.4	25.5	30	530	No	No brain damage, sacrificed 19 days later
183	6.2	25.8	30	620	No	No brain damage, sacrificed 20 days later
190	12	26.5	31.5	600	No	Dead late following day, hemothorax, intrapulmonary bleeding
191	8	26.5	31.5	600	No	Same
193	9.2	25	33	750	No	No brain damage, sacrificed 90 days later
246	11	26	35	950	Yes	No brain damage, sacrificed 100 days later
250	12	25	38	950	Yes	No brain damage, sacrificed 25 days later
272	9.8	26	35	1,000	No	Dead after rewarming, hemorrhagic atelectasis
283	10.5	25	34	870	No	No brain damage, sacrificed 30 days later

*The perfusion rate ranged between 1.6 and 4.7 c.c. per kilogram per minute maining 6. During the period of venous inflow occlusion, the pupils became widely dilated in all animals but normal pupillary constriction returned in each as rewarming took place.

Animals With Coronary and Carotid Artery Perfusion.—There were 28 dogs in this group. Heparinized blood was used in 13 (Table IV). The temperature ranged between 25° and 28° C. and the period of inflow occlusion from 29 to 38 minutes. The blood perfusion varied between 1.6 and 4.7 c.c. per kilogram per minute. In two instances, ventricular fibrillation occurred shortly after release of the vena caval clamps. Successful conversion to sinus rhythm was accomplished in both. In 12 animals, there was prompt recovery without evident neurologic damage. In 1 case, the animal was successfully rewarmed and regained consciousness but died with hemorrhagic atelectasis a short while later. Three additional dogs, following an apparently good imme-

TABLE V. CORONARY AND BRAIN PERFUSION WITH CITRATED BLOOD*

DOG NUMBER	WEIGHT OF DOG (KG.)	TEMPERATURE OF DOG (° C.)	TIME CAVAL OCCLUSION (MIN.)	BLOOD PERFUSED (C.C.)	VENTRICULAR FIBRILLATION	FINAL RESULT
208	9.3	25.5	35	800	Yes	No brain damage; sacrificed 112 days later
211	9.2	26	38	900	Yes—arrested by simple massage	Stuporous 5 days; died; fluid in chest, probable brain damage
223	13	25.5	28	820	Yes—arrested by simple massage	No brain damage; sacrificed 45 days later
230	10.5	24.5	35	1200	No	No brain damage; sacrificed 105 days later
236	10	25.5	35	1050	No	No brain damage; sacrificed 104 days later
241	10	26	35	875	No	No brain damage; sacrificed 90 days later
244	10.2	26	34.5	840	No	No brain damage; sacrificed 60 days later
255	12	26.5	30	650	Yes	No brain damage; sacrificed 39 days later
256	11	26	34.5	850	No	No brain damage; sacrificed 35 days later
261	13	25	34.5	700	No	No brain damage; sacrificed 34 days later
271	11.4	25	35	1100	No	Death; pulmonary edema after resumption of circulation, inadequate removal perfused blood
273	10	25	39.5	900	No	No brain damage; sacrificed 20 days later, empyema
274	10.6	26	35	850	No	No brain damage; dead 3 days after surgery, almost total atelectasis of lungs
314	11	25	32	870	No	Dead late day after surgery, hemorrhagic atelectasis of lungs
333	11	25	29	600	No	No brain damage; sacrificed 78 days later

*The perfusion rate ranged between 1.5 and 3.4 c.c. per kilogram per minute.

diate recovery, died late the day after surgery with hemothorax and hemorrhagic atelectasis. The remainder were in good health until sacrificed from 19 to 120 days after operation.

Citrated blood was used in 15 animals (Table V). The temperature ranged between 24.5° and 26.5° C. and the period of inflow occlusion between 29 and 39.5 minutes. The blood perfused varied between 1.5 and 3.4 c.c. per kilogram per minute. Ventricular fibrillation developed in 3 animals in which intracardiac calcium was given after release of the vena caval clamps and before cardiac massage was begun. Only 1 animal given intracardiac calcium after one minute of cardiac massage developed ventricular fibrillation. Conversion to sinus rhythm followed cardiac massage in 2 cases and in the other 2, electric shock was successfully employed. One animal (No. 271), which through error was given 400 c.c. more blood by perfusion than was removed, developed acute pulmonary edema shortly after release of vena caval occlusion and died. The remainder recovered, though 2 animals died one and three days after operation with hemorrhagic atelectasis. One exceptional animal was stuporous for five days after operation and then expired. He had been given a perfusion of 900 c.c. of blood during a period of thirty-eight minutes, or 2.5 c.c. per kilogram per minute. There was no evidence of neurologic impairment in the remainder. In no animal perfused with oxygenated blood into coronary and carotid arteries was even transient full pupillary dilatation observed.

DISCUSSION

These experiments demonstrated that perfusion of the coronary arteries alone with oxygenated blood lengthens to from twenty-five to thirty minutes the period of venous inflow occlusion compatible with recovery. Nearly one half of the animals, however, exhibited neurologic abnormalities for a short period following operation, though they recovered and remained well. When both coronary and carotid arteries were perfused, venous inflow occlusion could be maintained for from 29 to 39.5 minutes without evidence of neurologic damage. It seems clear that perfusion of the carotid, as well as of the coronary arteries, affords protection over and beyond that conferred by coronary perfusion. The fact that great protection results from coronary perfusion alone suggests that avoidance of neurologic damage is, to some degree, dependent upon protection of the heart itself during the period of inflow occlusion and prompt recovery of good cardiac function afterward.

We have not, ourselves, determined the upper limit of safe inflow occlusion in hypothermic animals without perfusion. We and others have subjected animals under moderate hypothermia to periods of caval occlusion of fifteen minutes with recovery. Gollan and his associates[11] reached the conclusion that even at body temperatures as low as 14° C. the hypothermic animal cannot withstand interruption of cardiac function for more than twelve minutes.

Edwards and his colleagues[12] found that a ventriculotomy performed on moderately hypothermic dogs during a 10-minute period of inflow occlusion invariably resulted in ventricular fibrillation, but that a low incidence of fibrillation was noted when ventriculotomy with production and closure of a septal defect was performed under similar circumstances but with coronary artery perfusion. Five of 7 animals survived inflow stasis for twenty minutes during perfusion of the heart, brain, and upper extremities. Shumway, Gliedman, and Lewis[13] demonstrated that coronary perfusion with either oxygenated or venous blood in moderately hypothermic dogs permitted one to occlude the venae cavae relatively safely for twenty minutes. Gaertner and his colleagues[14] have recently reported that coronary and brain perfusion extended the period of safe cardiac exclusion. In all of these experiments, the perfusion was carried out by means of a mechanical pump.

The perfusion rate in the experiments of Edwards and his associates was 10 and 20 c.c. per kilogram per minute. Shumway and his colleagues found that coronary perfusion with venous blood at a flow rate of 50 c.c. per minute was satisfactory for maintaining an acceptable degree of myocardial oxygenation. Gaertner, Kay, Isaacs, and Dever used a perfusion rate of from 80 to 120 c.c. of blood per minute.

Our experiences suggest that simple gravity flow, utilizing pressure in the infusion flask to regulate the speed, is adequate for both coronary, and carotid, and coronary perfusion. They further suggest that a rate of between 1.5 and 4.7 c.c. per kilogram per minute is adequate. Most of our animals were perfused at the rate of approximately 2.5 c.c. per kilogram per minute.

Shumway, Gliedman, and Lewis had no survivors when citrated blood was used. We have found that citrated blood can be used safely in dogs provided one massages the heart vigorously after release of the vena caval clamps, administers a small amount of calcium into the right ventricle, and uses electric shock for the occasional animal in which fibrillation develops and is not converted by massage alone.

Shumway and his associates noted troublesome bleeding when heparinized blood was used. This was also the experience of Gaertner and his colleagues who, however, had the impression that death in their animals was mostly due to pulmonary congestion. We encountered the same hemorrhagic difficulty when heparinized blood was used. In subsequent experiments,[15] this difficulty has apparently been overcome. It has been learned that delaying the perfusion for two minutes after occluding the venae cavae and maintaining respiration during this interval seemingly eliminates the hemorrhagic tendency. This plan permits the heart and lungs to be largely emptied of blood before the perfusion is started. Animals treated in this fashion have developed neither hemorrhagic atelectasis nor troublesome hemothorax.

Whether the studies reported will prove of real value in clinical cases, we do not know at this time. Judging from them, it would seem reasonable to suppose that protecting the patient by procaine blockade of the right atrial-superior vena caval junction and perfusing the coronary and carotid arteries with oxygenated blood will likely permit a relatively long period of inflow occlusion with minimal risk of ventricular fibrillation and neurologic sequelae.

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THE CREATION AND REPAIR OF INTERVENTRICULAR SEPTAL DEFECTS IN DOGS UTILIZING THE HEART-LUNG MACHINE

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SEVERAL different methods have been employed in attacking the problem of interventricular septal defects, but we feel a heart-lung machine which will oxygenate and pump adequate amounts of blood safely remains the ultimate goal. This group of experiments was undertaken to gain acquaintance with the problems inherent in application of our machine to this type of procedure and with an eye to clinical cases. Gibbon, Miller, Dobell, Engell, and Voight[1] reported a series of 20 dogs in which they used their heart-lung machine to close previously created interventricular septal defects, with eight deaths. Donald, Harshbarger, Hetzel, Patrick, Wood, and Kirklin[2] also closed interventricular septal defects using the Gibbon type heart-lung apparatus. Hypothermia was used by Taufic and Lewis[3] and by Scott, Collins, and Foster,[4] while Warden, Cohen, Read, and Lillehei[5] used controlled cross-circulation in the same type of work. Murray[6] described the use of a strip of fascia lata in the closure of interventricular septal defects without opening the ventricle in 1948.

METHOD

Mongrel dogs weighing from 9 to 33 Kg. are anesthetized with intravenous pentobarbital sodium and placed on controlled respiration. The right and left femoral veins and arteries are isolated in the groins and the right external jugular vein is isolated in the neck. The right chest is entered through the bed of the fifth rib and sling ligatures of umbilical tape are placed around the superior and inferior venae cavae adjacent to the right auricle. The azygos vein is tied. The animal is then given 2.5 mg. of heparin for each kilogram of body weight. A polyethylene catheter is inserted into the left femoral artery and attached to a Statham strain gauge so that blood pressures may be recorded throughout the procedure. Venous blood is collected from the animal by a plastic catheter (No. 14 Fr.), inserted into the superior vena cava through the external jugular vein, and by a second catheter into the inferior vena cava through the right femoral vein. A metal cannula is inserted into the right femoral artery to return the blood from the heart-lung machine to the dog.

A Foley catheter is placed within the right atrium, and the balloon distended to the point where it occludes the tricuspid orifice. During the ventriculotomy, blood returning to the right atrium through the coronary sinus is carried to the oxygenator through the lumen of the catheter.

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The dog's heart and lungs are excluded from the circulation by occlusion of the superior and inferior venae cavae with the sling ligatures Venous blood flows by gravity through a constantly recording rotameter and is filmed on stainless steel screen discs which are slowly revolving in an atmosphere of oxygen at room temperature The blood is collected below the discs and passes through a bubble trap, consisting of a stainless steel sponge coated with Dow Corning Anti Foam A A modified Dale Schuster pump forces blood back into the arterial system of the dog through the cannula in the right femoral artery The flowmeter, oxygenator, bubble trap, and modified Dale Schuster pumps have been described in detail in an earlier paper from this laboratory [7] The assembled oxygenator is sterilized by autoclave, and the pumps and tubing are sterilized with 10 per cent formaldehyde solution Eleven hundred milliliters of blood are required to prime the system Clotting is prevented by the addition of 40 mg of heparin (Connaught Laboratories) to each liter of freshly drawn arterial blood

A 5 to 6 cm incision is made over the outflow tract of the right ventricle A defect, approximately 2 cm long, is made in the interventricular septum so as to avoid the conduction system insofar as possible The defect is closed with three to five interrupted silk sutures The ventriculotomy is closed with interrupted silk sutures The perfusion is terminated and the cannulae removed

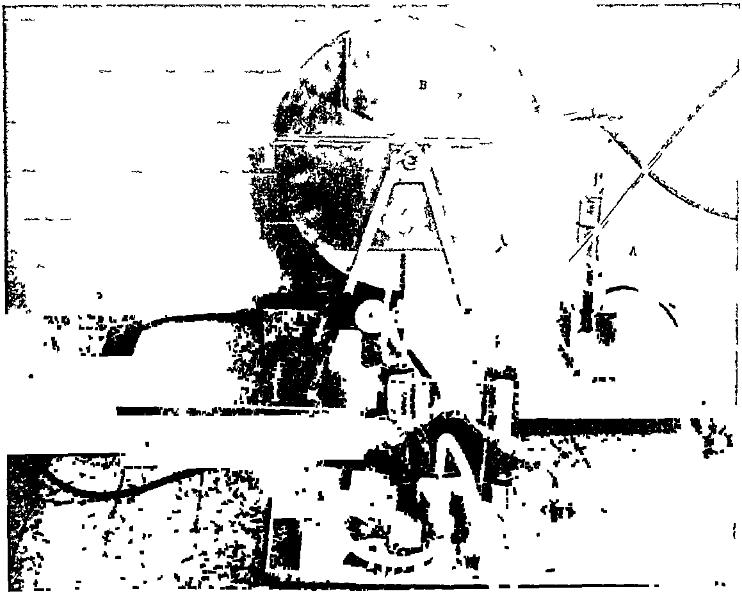

Fig 1 — A Flowmeter B Oxygenator C, Bubble trap D Modified Dale Schuster pump

A protamine heparin titration is performed on blood samples just before the perfusion ends to estimate the amount of protamine needed to return the clotting time to normal The estimated protamine is given in 100 ml of 5 per cent glucose in water over a period of approximately fifteen minutes Subsequent protamine titrations are performed every twenty to thirty minutes for an hour, and additional protamine is given as need [illegible] A [illegible]h whole

TABLE I. PERFUSION DATA

DOG NUMBER	WEIGHT (KG.)	FLOW (C.C./MIN.)	ARTERIAL SAMPLES—PREPERFUSION					ARTERIAL SAMPLES—END OF PERFUSION						RESULT
			PH	HCO_3 (MEQ./L.)	PYRUVATE (MG %)	O_2 CONTENT (VOL. %)	CO_2 CONTENT (MM./L.)	PH	HCO_3 (MEQ./L.)	PYRUVATE (MG.%)	O_2 CONTENT (VOL. %)	O_2 SATURATION (%)	CO_2 CONTENT (MM./L.)	
36	14.6	—	—	—	—	—	—	—	—	—	—	—	—	Survival
131	19.5	800	7.23	26	0.7	—	24.62	7.36	16	1.0	13.98	81	14.55	Survival
132	25.7	750	7.07	31	—	—	27.93	7.59	14	—	20	108	11.50	Survival
144	15.5	400	7.53	—	—	—	—	7.46	8	—	20.39	92	7.2	Survival; bled
146	19.5	600	7.29	16	—	20.57	14.33	7.45	12	—	22.97	98	9.66	Died
150	21	550	7.48	20	—	19.13	15.53	7.55	13	—	21.2	99	9.09	Died
153	15.5	—	7.56	18	—	17.80	15.40	7.70	11	—	17.58	108	8.46	Survival
157	24	—	7.44	20	2.2	19.00	17.46	7.40	12	3.2	15.95	88	10.26	Survival
159	9	—	—	—	—	—	—	7.42	—	—	—	—	—	Survival
165	9.7	—	—	—	—	—	—	7.60	—	—	15.74	89	9.50	Survival
167	29.3	1500	7.37	14	—	21.44	12.52	7.58	7	—	18.88	95	6.90	Survival
168	33.5	800	7.34	16	1.9	23.33	14.12	7.37	—	2.2	11.09*	55	13	Survival
193	23.8	1000	7.58	20	1.2	19.95	16.73	7.59	16	1.9	16.2	90	12.90	Survival
194	28.2	800	7.43	21	1.2	20.90	17.80	7.53	16	2.2	18.6	85	12.40	Survival; bled
195	14	600	7.56	16	1.0	22.80	12.79	7.58	—	2.6	18.63	102	7.50	Survival
246	18.2	850	7.44	26	1.4	18.23	22.46	7.65	14	1.8	18.01	109	11.78	Survival
249	14.8	600	7.59	15	2.1	20.56	12.71	7.67	12	2.6	19.46	101	8.87	Survival
Average	19.7	770	7.42	19.9	1.47	20.34	17.26	7.53	12.6	2.1	17.91	96	10.24	15 Survived 2 Died

*Not included—technical error.

blood transfusion, amounting usually to one fourth to one third of the estimated blood volume, is given as soon as the protamine has been administered A thoracostomy tube is inserted on either side and attached to water seal drainage, and the chest is closed During the postoperative period, a careful check is kept on the drainage from the chest and additional fresh whole blood is given as indicated.

The essentials of the heart lung apparatus are demonstrated in Fig 1,* and a diagram of the perfusion circuit is indicated in Fig 2.*

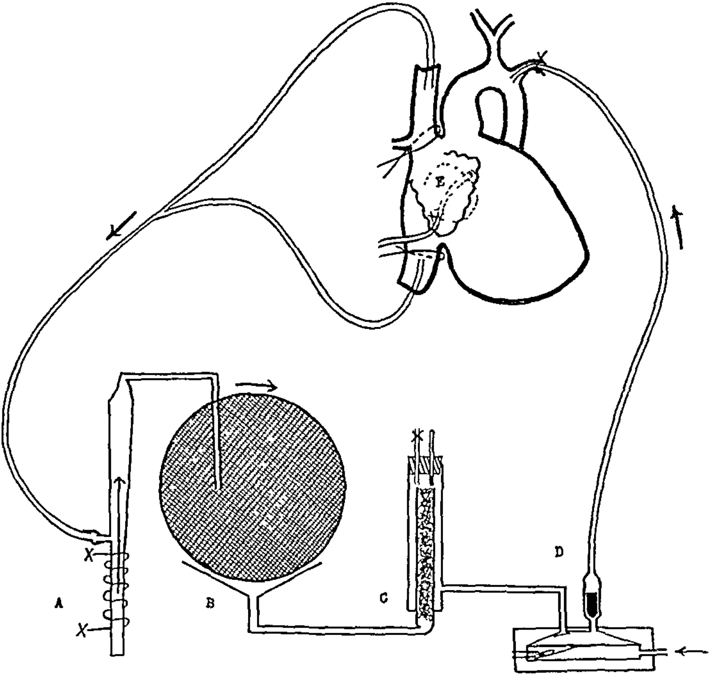

Fig 2—*A*, Flowmeter *B*, Oxygenator *C*, Bubble trap *D*, Modified Dale-Schuster pump compressed air enters at arrow *E*, Foley catheter in right atrium

RESULTS

Seventeen animals were operated upon as described Fifteen survived and 2 died One death resulted from a pneumothorax which developed when a thoracostomy tube became disconnected from the water-seal system in the early postoperative period The second death resulted from occlusion of the chest drainage tubes, and the animal died of a hemothorax and bilateral compression atelectasis

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Two animals required re-exploration for excessive bleeding from the chest. One dog lost 350 ml. of blood from the chest in a short period, and when re-explored was found to be bleeding from the tip of the auricular appendage. The second dog lost 500 ml. of blood from the chest in one hour, and upon re-exploration was found to be bleeding from a mediastinal vessel. Both dogs recovered after the second operation. In the remaining dogs the average postoperative blood loss into the water-seal bottles was 180 ml.

The average weight of the dogs was 19.7 Kg. The average flow rate during perfusion was 770 ml. per minute or 39 ml. per kilogram body weight per minute. The blood pressure averaged 80 mm. Hg systolic and 40 mm. Hg diastolic during the perfusion.

Arterial saturation during perfusion averaged 96 per cent for 16 of the dogs. The CO_2 concentration regularly fell almost 50 per cent below control levels. The blood pyruvate level rose from an average control level of 1.47 mg. per cent to 2.1 mg. per cent at the end of perfusion. The blood pH rose from the control average of 7.42 to 7.53 at the end of perfusion. The average total time of perfusion was thirty-eight minutes, and the average blood loss was 560 ml. during the cardiotomy. All the data are summarized in Table I.

DISCUSSION

The advantages in using a heart-lung machine in ventricular septal surgery, over other methods such as refrigeration and blind suture, are several. With it, intracardiac procedures can be carried out unhurriedly in a relatively dry field. Diagnosis of the type of lesion can be accurately determined and precise repair carried out only in the presence of direct vision. Perfusion during the procedure insures an adequate supply of oxygen to all tissues at all times.

There are hazards in the use of an extracorporeal system. The problem of uncontrolled bleeding following perfusion because of inability to restore the clotting mechanism to normal has been seen in the past but was not encountered in this group of animals. We feel that good metabolic preparation of the dogs, avoidance of excessively prolonged perfusion, operation of the apparatus so as to minimize undue trauma to the formed elements of the blood, accurate back-titration of heparin with protamine, and replacement of unknown clotting factors by fresh blood transfusion at the end of the procedure[8] are all factors in this accomplishment. Continued excessive postoperative blood loss from the chest tubes after the circulating heparin has been neutralized and fresh blood has been given is an indication for re-exploration of the subject.

Air embolism was not a problem in this group of animals. We feel that a system which uses gravity alone to drain the venae cavae is safer than pumping systems which reduce the pressure of contained blood below that of the atmosphere, for such low pressures invite bubble formation both from effervescence and from leaks into the system from the surrounding atmosphere. The mechanisms by which negative pressures are avoided have been previously described.[7]

Oxygenation at the end of perfusion averaged 96 per cent for 16 of the subjects. One dog. (No. 168) was not included in the average since the oxygenator was not functioning properly through a technical error. The level of fixed acids rose during the procedure and tended to offset the average 50 per cent fall in CO_2 concentration The blood pH rose from a control level of 7 42 to 7 53 at the end of the procedure It does not appear to be necessary to add carbon dioxide to the oxygen run into the oxygenator The mean control plasma hemoglobin was 18 8 mg per cent, while the mean plasma hemoglobin at end of perfusion was 86 mg per cent This is far below the amount required to cause renal damage[9]

Ventricular fibrillation occurred during cardiotomy in 6 of the 17 dogs, and was present thirteen to twenty-eight minutes Undoubtedly, one factor in the initiation of fibrillation was injury to the conduction system at operation No difficulty was encountered in defibrillating the hearts with electrical discharges of 0 1 second at 1 75 amperes Undoubtedly adequate myocardial perfusion throughout was a factor in this ease of defibrillation, as Senning has shown[10] Following defibrillation, the hearts developed a 3 1 atrioventricular block, initially This shortly changed to a 2 1 block, and within a few minutes to a normal sinus rhythm

The two deaths in this series emphasize the importance of postoperative care The lungs must expand completely, all blood must be evacuated from the thoracic cavity, the tubes must remain patent, the position of the animal must be changed frequently

The inflated Foley catheter in the right atrium serves to return the coronary blood flow directly to the oxygenator and materially reduces the over all blood loss during the procedure The coronary sinus return in a 15 Kg dog during perfusion is from 40 to 50 ml per minute (our measurements), and in large dogs is proportionately more Blood from the suction bottle has on occasion been returned directly to the system and no difficulty has been encountered This we prefer not to do as the average plasma hemoglobin of this blood is 325 mg per cent, and we suspect such return to contribute to late problems of hemostasis In general, the blood loss at operation becomes smaller as the techniques are mastered by the operators and operating time is reduced

The average ventriculotomy incision in the dogs was 5 5 cm in length Speculation as to the ultimate fate of these wounds, and whether or not aneurysms would develop, is still unsettled, although they have not been seen in dogs sacrificed up to twelve months after ventriculotomy

CONCLUSION

The heart lung apparatus previously described by this group has been employed in the creation and repair of interventricular septal defects in 17 consecutive dogs, with two deaths There were no deaths as a result of machine failure

Advantages of a heart lung machine as outlined have been that it is possible to operate within the heart in an unhurried and safe manner in a relatively dry field, and that diagnosis and repair of the lesion
more precisely than by blind or hasty methods

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Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-seventh Annual Meeting of The American Association for Thoracic Surgery will be held May 4, 6, and 7, 1957, in Chicago, Illinois. Headquarters will be at the Palmer House.

Requests for Hotel Reservations

These should be mailed directly to Mr. Edward Langford, Reservations Manager, Palmer House, Chicago. Please mention this Association, the type of accommodation desired, the date, and approximate hour of arrival and departure. If accommodations are desired elsewhere in Chicago, please communicate directly *with the hotel of your choice.*

Thoracic Surgery Forum

The Thoracic Surgery Forum will be continued as a special session at the 1957 meeting. The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies, and modified or new surgical techniques. The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferal to the Regular Program.

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper.

All Thoracic Surgery Forum papers will be published together in one issue of the JOURNAL. Maximum length: 3000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts of Papers

Abstracts of all papers for presentation at the 1957 meeting must be received on or before Dec. 15, 1956, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Thoracic Surgery Forum," or "For Regular Program." The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Five, repeat, five copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 600 South Kingshighway, St. Louis 10, Missouri.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. Karl P. Klassen, The Ohio State University, Columbus 10, Ohio, before Dec. 15, 1956.

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions. If the films are well labeled, it will not be necessary for the author to be present for comment.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec. 15, 1956, otherwise the application will be deferred for consideration until the 1958 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. O. T. Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn.

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year. The new letters of recommendation should also be sent to Dr. Clagett, the Chairman of the Membership Committee.

The Journal of Thoracic Surgery

Vol. 32 October, 1956 No. 4

Original Communications

A COMPARISON OF TWO SYSTEMS OF ANESTHESIA FOR THORACIC SURGERY

Ether versus Thiopental-Succinylcholine

Henry K. Beecher, M.D.
Boston, Mass.

In comparing any two systems of anesthesia, it will be profitable to keep in mind the effectiveness of each in permitting the anesthetist to overcome the chief problems of the type of surgery involved. In thoracic work the principal hazards to be overcome by the anesthesia system or by the anesthetist are as follows: obstructing secretions, troublesome vagal reflexes of the respiratory and circulatory systems, anoxia, elevation of carbon dioxide tension, circulatory strain, motion within the thorax, and finally the hazard of explosion.

At the present time I should like to compare (a) ether anesthesia, as carried out traditionally for many years for thoracic surgery, and (b) thiopental sodium-succinylcholine chloride anesthesia (Pentothal-Anectine). For a considerable period we have been using the thiopental-succinylcholine sequence at the rate of about 4,000 cases per year for all types of major surgery, including the longest and most complicated thoracic procedures, in order to get firsthand insight into its advantages and limitations. We believe that this agent has, because of its greater controllability, considerable superiority over the various forms of curare utilized for much the same purpose over the past decade and a half. Now to consider the principal hazards.

Obstructing Secretions.—Both ether and succinylcholine produce in many subjects a rather heavy flow of saliva and mucus. This is objectionable but

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From the Anesthesia Laboratory of the Harvard Medical School at the Massachusetts General Hospital, Boston, Mass.

Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

not difficult to handle with either system of anesthesia, inasmuch as these secretions can be easily aspirated through the universally employed endotracheal tube. In sudden emergencies of obstruction of the airway, as from profuse secretions or blood, the muscle relaxant system permits swifter control of the situation.

Troublesome Vagal Reflexes of the Respiratory and Circulatory Systems.—Cough, of course, normally depends on local irritation in air passages and it can be initiated elsewhere by stimulation of afferent vagal fibers. The reflex arc is completed by motor nerves which carry efferent impulses to the intrinsic and accessory muscles of respiration. Effective cough requires a closed chest wall, but cough can still spread the contents of the lungs and bronchial tree even though its effectiveness be somewhat aborted by the open chest. A considerable depth of anesthesia is sometimes required to obliterate cough under ether. The muscle relaxants appear to be superior and succinylcholine can be used to control cough absolutely and with only a light level of anesthesia. Cough, in conjunction with light ether anesthesia, may be particularly dangerous during certain stages of intrathoracic procedures. In the patient in poor condition, the considerable depth of ether anesthesia required to abolish cough may seriously depress the patient's blood pressure. Succinylcholine, with its transient action and easily varied depth of muscular paralysis, is better than ether for control of cough.

Anoxia.—With properly managed anesthesia, anoxia is rarely a serious hazard in thoracic surgery any more. In earlier days, patients with profuse purulent secretions in the airway were a commonplace. It was sometimes difficult to maintain in them a satisfactory airway and adequate oxygenation, but with the advent of chemotherapeutic agents this problem has been largely overcome. One anesthesia regime is as good as the other in the majority of cases as far as oxygen supply goes, except in cases of obstruction of the airway when swift intubation and aspiration are essential. In this case, the muscle relaxant sequence is the better, as mentioned. This system is also probably better when severe emphysema is present, used with a ventilator which provides for the use of negative as well as positive pressure.

Elevation of the Carbon Dioxide Tension.—A far greater and more common problem in thoracic surgery than that of anoxia is that of an elevated tissue carbon dioxide tension, as Miss Murphy and I first showed with factual data (Beecher and Murphy,[1] 1950) and as many others have since confirmed. With ether anesthesia (Beecher, Quinn, Bunker, and D'Alessandro,[2] 1951) in the most difficult situation, namely, that of pneumonectomy, we were never able with the "educated hand" squeezing the bag to get the carbon dioxide tension to normal levels, although this was quite easy in the lobectomy group.

The last time Dr. Gibbon and I discussed this question, comparing, in pneumonectomy cases, machine methods with our manual ones, I thought we still had a little the better of the argument[2] inasmuch as pneumonectomies on the machine showed 74 mm. of mercury carbon dioxide tension and ours by hand 58 mm. of mercury tension. Since that time, however, ventilators have been improved and we have been particularly well pleased with the Jefferson *ventilator, which makes possible the simple use of varying degrees of positive* or negative pressure. Unless the anesthetist has sticky fingers, it is not possible for manual ventilation to produce negative pressure in the airway. We have not yet got around to running a series of carbon dioxide tensions in patients undergoing pneumonectomy and on the ventilator, but there is no doubt in my mind that one could easily maintain carbon dioxide tension at a normal level with this improved ventilator in conjunction with the use of muscle relaxants. We hope to obtain factual data on this score, perhaps others have already done so. It is possible to use the ventilating machine with ether. It is my impression that this is sometimes more difficult with ether than with succinylcholine.

Undoubtedly it is desirable for the anesthetist to get from time to time the "feel of the bag" by manual use. By so doing he can appraise the ease or difficulty of inflation of the lungs. Properly designed ventilators make the shift to hand use possible without difficulty.

Circulatory Strain.—The strain on the circulation produced during open thoracic procedures is undoubtedly great, judging by the response of patients to such procedures. It has long been our contention that the crippled cardiovascular system of elderly individuals stands ether anesthesia very well indeed. There is much evidence to support this. We have never supposed, however, that ether was perfect in this regard. It will be very important to run a carefully controlled series of alternate cases with the two systems in order to settle the matter of which produces the greater strain on the circulatory system. I do not know the answer to this, nor do I believe anyone else does as yet. I can only say at the present time that we have been very well pleased with our experience using the thiopental succinylcholine technique for prolonged and difficult transthoracic procedures such as esophagectomy, transthoracic gastrectomy, and so on.

We have long believed that it was important to alternate cases and to try to study in a factual way these two systems of anesthesia. So far we have had very great difficulty in convincing anyone else of the importance of this to the extent of *getting financial support* for such a study. I do not believe it is possible, within a reasonable period of time, to arrive at the correct answer to this question without such a comparative study. While a good many people raised a considerable protest over our death rate study (Beecher and Todd,[3] 1954), where we showed among other things that the deaths during *induction* of anesthesia were more than five times higher when muscle relaxants were used than when they were not, no one has yet obtained evidence contradicting those findings. It should, of course, be kept in mind that those observations were based largely on curare type agents, not on the newer succinylcholine. There is need for a careful comparison of the two systems of anesthesia discussed here. One's conclusions must not be hastily arrived at. I should like to point out that to cast up even a *rough appraisal of deat*
most statisticians require no fewer than ten dea nose for a
that the death rate from anesthesia is at the a of
will still take 1,000 cases to demonstrate that

this and other reasons, an adequate comparison will be a tedious, time-consuming, and expensive proposition. The alternate cases procedure urgently needs to be carried out.

Answers to many questions are wanted in this connection. We need to have more information than we have as to what the comparative effects of the two systems of anesthesia may be on the circulating blood volume. There is some evidence of peripheral stagnation, for example, in the tendency of the fingers and toes to be quite cyanotic under the thiopental-succinylcholine regime as compared with ether, while the blood in the thorax or abdomen is properly oxygenated. One needs to know how extensive and significant the rather obvious stagnation may be under the thiopental-succinylcholine system. This cannot be settled in an easy chair. The extent of this disability can be determined only by painstaking studies. There are plenty of unsolved problems here which can be settled by the comparative type of study just mentioned.

Motion within the Thorax.—While surgeons vary greatly as to how much motion within the thorax they will tolerate, unquestionably quietness is always an advantage and an urgent necessity at some phases of most intrathoracic procedures. The muscle relaxant system provides this more dependably than does ether.

The Hazard of Explosion.—I have always considered myself lucky that the surgeons at the Massachusetts General Hospital consider the use of the cautery or diathermy as contraindicated for surgical reasons. They do not use it in the chest. In the hospitals where such use is the custom, or desired, a nonexplosive procedure is necessary. In addition, there is the small but definite hazard of explosion of ether for unknown reasons. The thiopental-succinylcholine sequence solves this problem; ether does not.

Miscellaneous Points.—Thiopental was long ago discredited in the bled-out patient, the patient in shock, the patient with myocardial disease, the patient with severe asthma. We need to know whether the thiopental-succinylcholine system is as safe as ether for such cases. The proposed alternated case study would eventually give sound answers to these questions. I have had some difficulty in a case or two with the ventilator in very obese patients. Finally, I think there is no question as to what the results will be if untrained anesthetists, if war comes, suddenly begin to use the muscle relaxants in severely wounded or even scarcely wounded men. Thiopental alone, in North Africa in 1942 and 1943, was a fearful agent of death. The problem will be greatly compounded by the muscle relaxants in the hands of inexperienced anesthetists. One can hope that those charged with military policy planning are giving this problem the attention it deserves.

SUMMARY

The hazards in thoracic surgery which concern the anesthetist have been considered in terms of whether they are best overcome by ether anesthesia or by thiopental-succinylcholine. After a considerable use of the latter system for prolonged and difficult operations for thoracic surgery the following points emerge.

Obstructing secretions These can be handled equally well under th systems in ordinary cases When profuse purulent secretions or bloo struct the airway and constitute a sudden emergency, the muscle rela sequence is better

Troublesome vagal reflexes in the respiratory and circulatory sys Cough and other troublesome variations of respiratory force and rate ca best controlled by the muscle relaxant sequence

Anoxia: Anoxia should be easily prevented with either system of thesia In acute emergencies as when serious bleeding occurs or when the way becomes obstructed, speed of intubation and aspiration may be im tant This can be more quickly and efficiently taken care of with the m relaxant sequence

Elevation of carbon dioxide tension There seems to be little doubt ventilator systems have now been developed to the point where they are r effective than the manual bag squeezing system in maintaining adequate tilation It is my impression that ventilators work better with the mu relaxants than when ether is used

Circulatory strain It will take a good deal more experience than an has had to the present time to settle the question of which system is be tolerated by the circulatory system during open thoracic anesthesia T are reasons to believe that the extensive use of thiopental with the mu relaxant may constitute a considerable hazard Certainly past experience indicated that thiopental is exceedingly poorly tolerated by bled out indi uals or by those with crippled cardiovascular systems The tendency to ripheral stagnation of blood with the thiopental succinylcholine sequence or may not be important It is impossible to say at the present time how nificant this may be The matter needs study

Motion within the thorax Muscle relaxants undoubtedly permit m dependable control of this than ether does

Hazard of explosion There is no hazard of explosion when the thiopen muscle relaxant sequence is used

CONCLUSION

It can be seen from the above comments that the thiopental succin choline sequence provides a better solution to all problems encountered, w the exception, but a crucial question still remains as to how morbidity a mortality of the two systems will compare A far wider experience will required to settle these matters than as yet has been possible for anyo There is a great need for a systematic alternation of cases in large numb

A CONSIDERATION OF PROPER METHODS IN THORACIC ANESTHESIA

E. M. Papper, M.D., and Hugh F. Fitzpatrick, M.D.* (by invitation)
New York, N. Y.

IN RECENT years, interest and study in thoracic surgery have been concerned with the important physiologic disturbances associated with intrapleural operation and with the development of many improvements in surgical technique including the development of vessel prostheses. Vital as these interests are, they have unwittingly shifted the focus of clinical concern away from the relatively simple practical problems that often make for success or failure in the anesthetic or surgical management of the thoracic surgical patient. It is the purpose of this paper to review and remind surgeons and anesthesiologists of the physiologic and clinical abnormalities which may occur during some essential and simple anesthetic procedures. Obviously no relationship between these changes and mortality or even morbidity can be assessed with certainty. However, it is suggested that serious disturbances of ventilation or circulation may be the consequence of even subtle difficulties with procedures as simple and as common as laryngoscopy and endotracheal intubation.

ENDOTRACHEAL INTUBATION AND ITS EFFECTS

It is hardly necessary to remind thoracic surgeons that any of the premedicant sedatives, any anesthetic agent, and the skeletal muscle relaxant drugs may cause hypoventilation. It is also well known that the consequences of hypoventilation are anoxia and respiratory acidosis. However, it has not always been appreciated either in clinical care or in scientific study that apparently minor events, frequently unrecognized, may also contribute to the development of hypoventilation. Endotracheal intubation is a commonplace occurrence in thoracic surgery but the possible relationship to "malventilation" has not been sufficiently heeded. Disturbed breathing may begin with laryngoscopy. There are very few data which indicate the effect on gas exchange of the time required to perform laryngoscopy and endotracheal intubation. In at least one study[1] showing little change of blood pressure on direct recording during laryngoscopy and intubation of approximately 30 seconds, it was believed that this procedure caused no serious harm to the circulation or gas exchange. It

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From the Anesthesiology and Surgical Services, The Presbyterian Hospital and the Departments of Anesthesiology and Surgery, Columbia University, College of Physicians and Surgeons, New York 32, N. Y.

Supported in part by a research grant H-819-C from the National Heart Institute, of the National Institutes of Health, Public Health Service and by a medical research grant from the National Tuberculosis Association, through its Medical Section, the American Trudeau Society.

Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

*Present address: St. Luke's Hospital, New York, N. Y.

is fairly common, however, to intubate leisurely without making a deliberate effort to reduce the time between effective breaths consumed by the procedures of laryngoscopy, intubation, and restoration of effective ventilation

If the patient has been ventilated with a high concentration of oxygen anoxia does no develop However, the longer that ineffective ventilatory movements exist, the greater the probability of retention of carbon dioxide Measurements in our laboratories showed an increasing acidosis in the induction or "para intubation" period[2] (Fig 1) Frequent observations at 2 to 3 minute intervals were necessary to ascertain this pattern of development of acidosis and were made possible by Holaday's modification of the glass electrode[3] There were few instances in which acidosis did not occur whether breathing was spontaneous, assisted, or controlled in the "para intubation" period This complication can usually be prevented if the time between effective breaths is shortened to 30 seconds or less

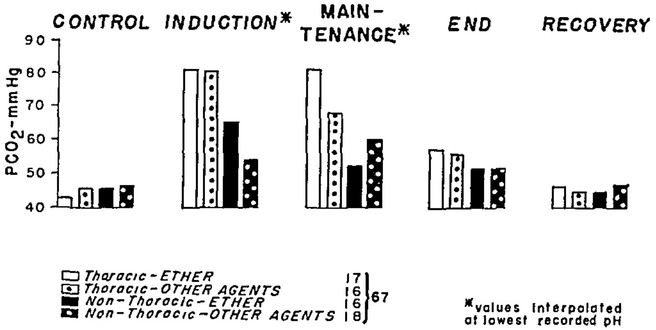
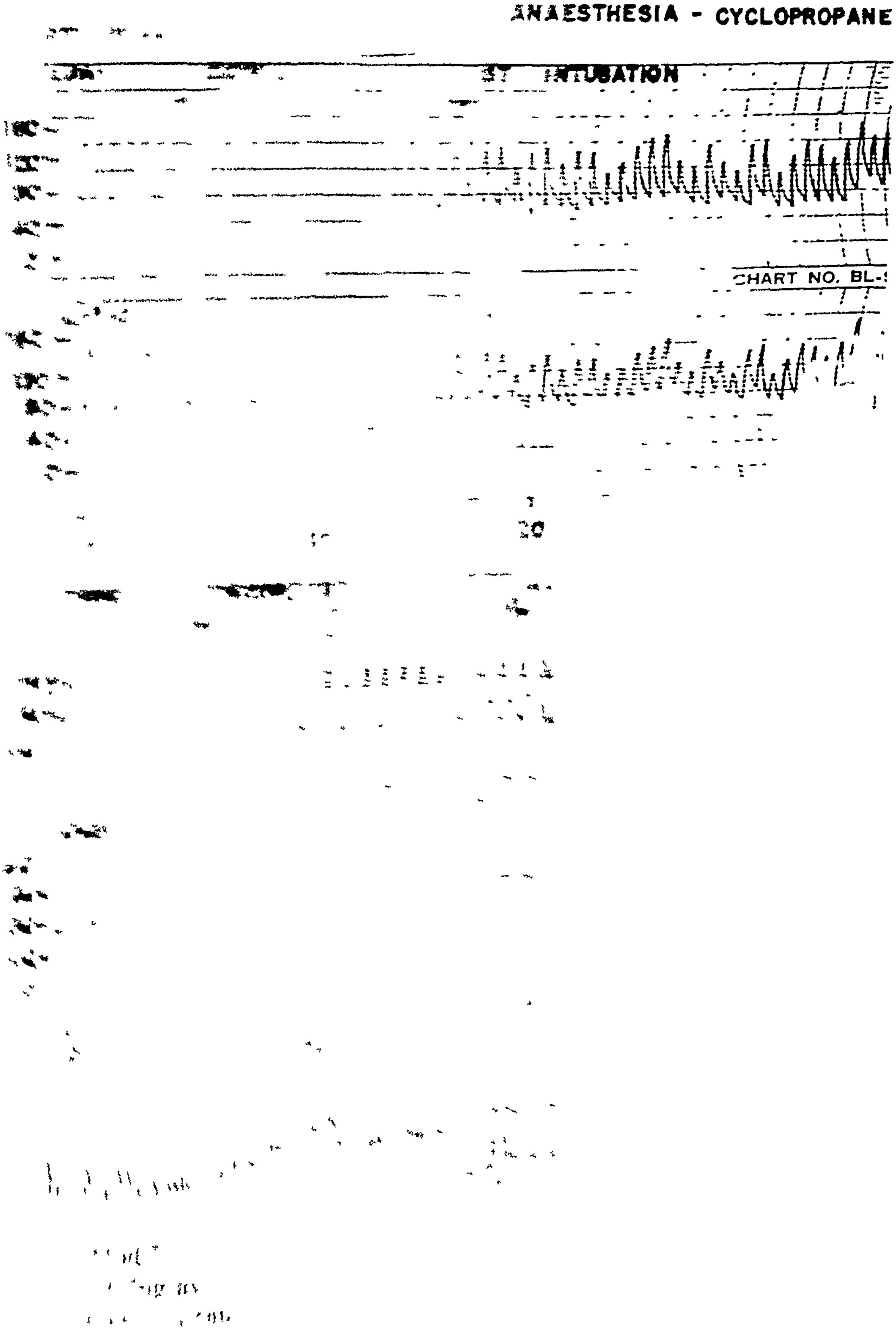


Fig 1 —Summary of pCO$_2$ in arterial blood at various times during anesthesia and operation Induction period extends from beginning of anesthesia and ends after endotracheal intubation Respiratory acidosis is associated with the hypoventilation of deepening anesthesia and undue prolongation of the time between effective breaths

Although speed is not a desirable goal in itself, it appears reasonable that the time between breaths should be no longer than 30 seconds in the hands of the average skilled anesthesiologist

The implications of retention of carbon dioxide during the laryngoscopy and intubation period are the same as at any other time This period of acidosis may produce electrocardiographic changes and potentiate vagal reflexes, quite important in view of the fact that an endotracheal tube is to be inserted immediately

Another by-product of the appreciation that endotracheal intubation should be accomplished with skillful dispatch was the demonstration that technical difficulties and errors may effect undesirable circulatory consequences In Fig 2 the tracings of the left brachial artery and left femoral artery were made during laryngoscopy and intubation At the first intubation, the irregularity in arterial pulses is quite obvious This is the result of inadequate relaxation for intubation The second intubation shows an uncomplicated and [illegible] of the manipulation of the [illegible] and taught by most people [illegible] frequently and routinely during [illegible] wise and necessary if there



Occasionally an endotracheal tube is inserted too deeply. Fig. 4 shows the correction of the circulatory disturbance when the tube is withdrawn from the region below the carina. It must be emphasized that this circulatory disability might not have been detected by ordinary auscultatory measurement of the blood pressure. It is most important to examine the chest thoroughly after intubation to make certain that the tube was placed correctly.

Burstein and his collaborators showed that electrocardiographic changes following endotracheal intubation consist in general in increases in rate and a variety of arrhythmias, the most common of which is sinus tachycardia. They concluded from these observations that circulatory changes incident to the manipulation of the airways were frequent, occurred in the majority of patients, and were due to increases in sympathetic rather than vagal tone.[4, 5]

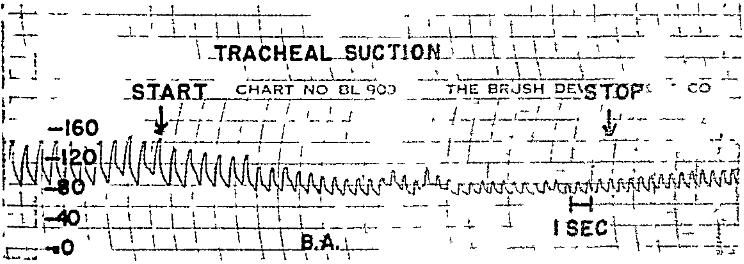


Fig 3 —Marked diminution in blood pressure during endotracheal suction

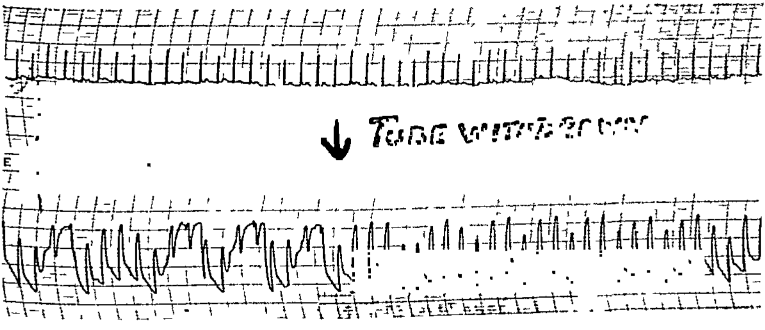


Fig 4 —Correction of irregularity of pulse contour by withdrawing an endotracheal tube into the upper trachea

King and his associates extended these observations and disputed some aspects of them in further studies.[1] They showed that intubation of the trachea uniformly produced an increase in blood pressure and an increase in heart rate. As anesthesia was deepened, these changes were less important. The circulatory changes did not appear to be related to any specific agent but were minimized with increasing depth of anesthesia.

unaffected circulation. Another interesting result of the manipulation of the endotracheal tube is shown in Fig. 3. It is believed and taught by most people that endotracheal tubes should be suctioned frequently and routinely during intrapleural operation. This procedure is obviously wise and necessary if there is blood or secretion in the airway. It is not a reasonable maneuver if there is nothing available to suck and particularly if one realizes that endotracheal suction may cause harm to the circulation.

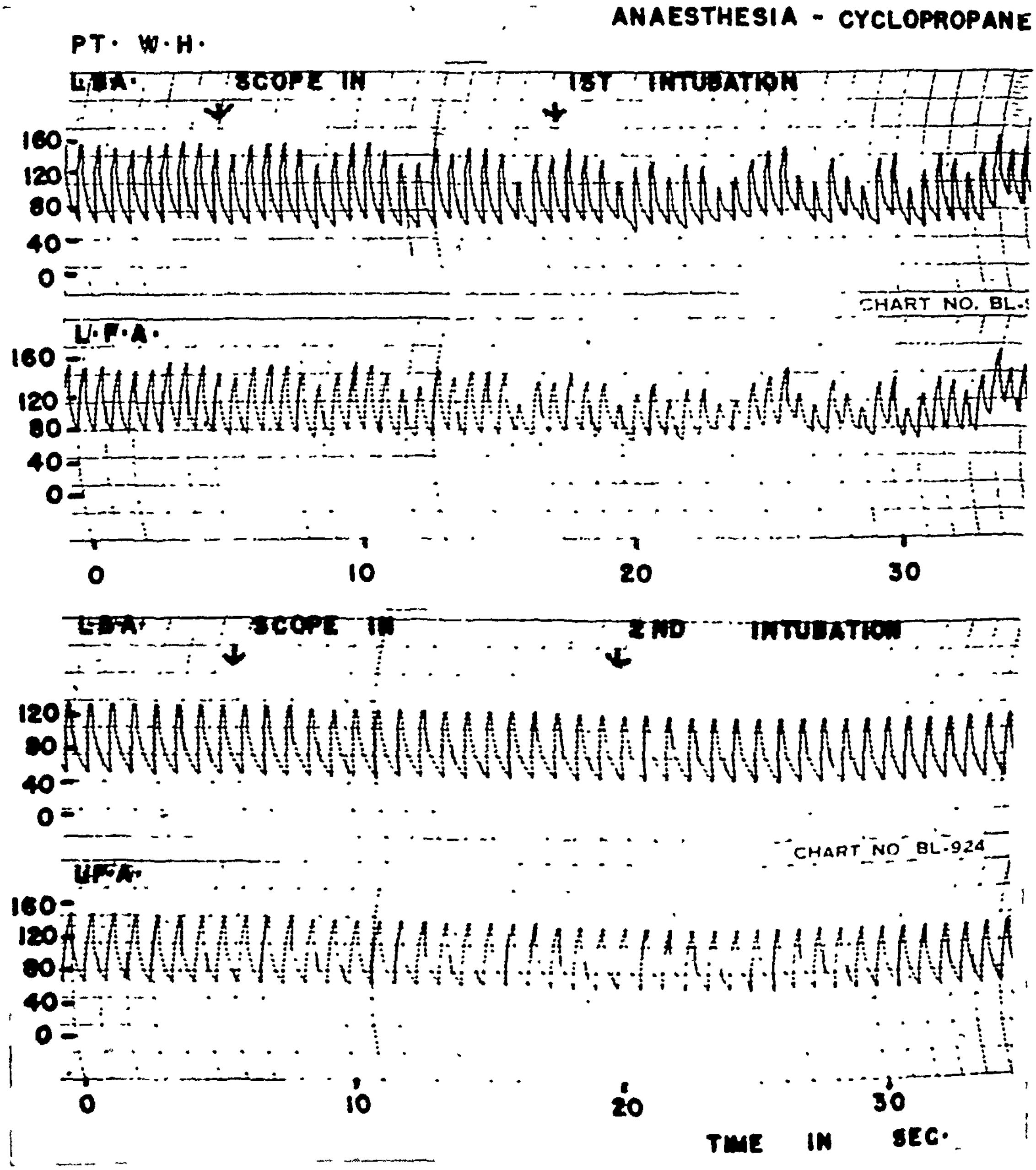


Fig. 2.—Lilly Capacitance Manometers and Brush Recorder used. Time interval marked in seconds. Tracings (upper) of left brachial artery and (lower) left femoral artery. Irregularity of pulse pressure noted during first intubation when relaxation was inadequate. Second intubation during adequate relaxation is without consequences.

Occasionally an endotracheal tube is inserted too deeply. Fig 4 shows the correction of the circulatory disturbance when the tube is withdrawn from the region below the carina. It must be emphasized that this circulatory disability might not have been detected by ordinary auscultatory measurement of the blood pressure. It is most important to examine the chest thoroughly after intubation to make certain that the tube was placed correctly.

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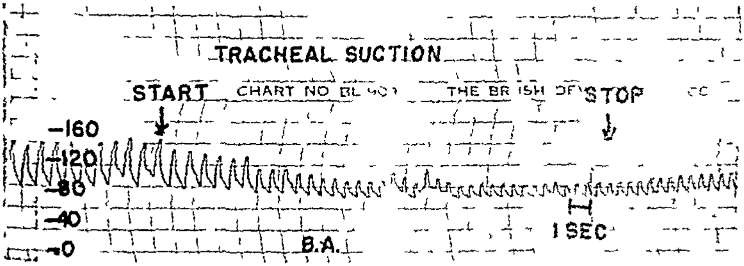

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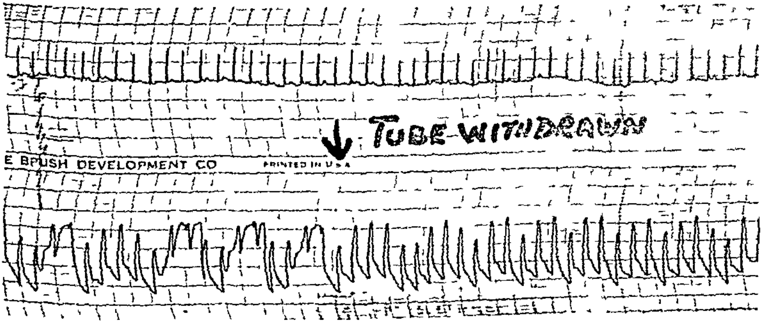

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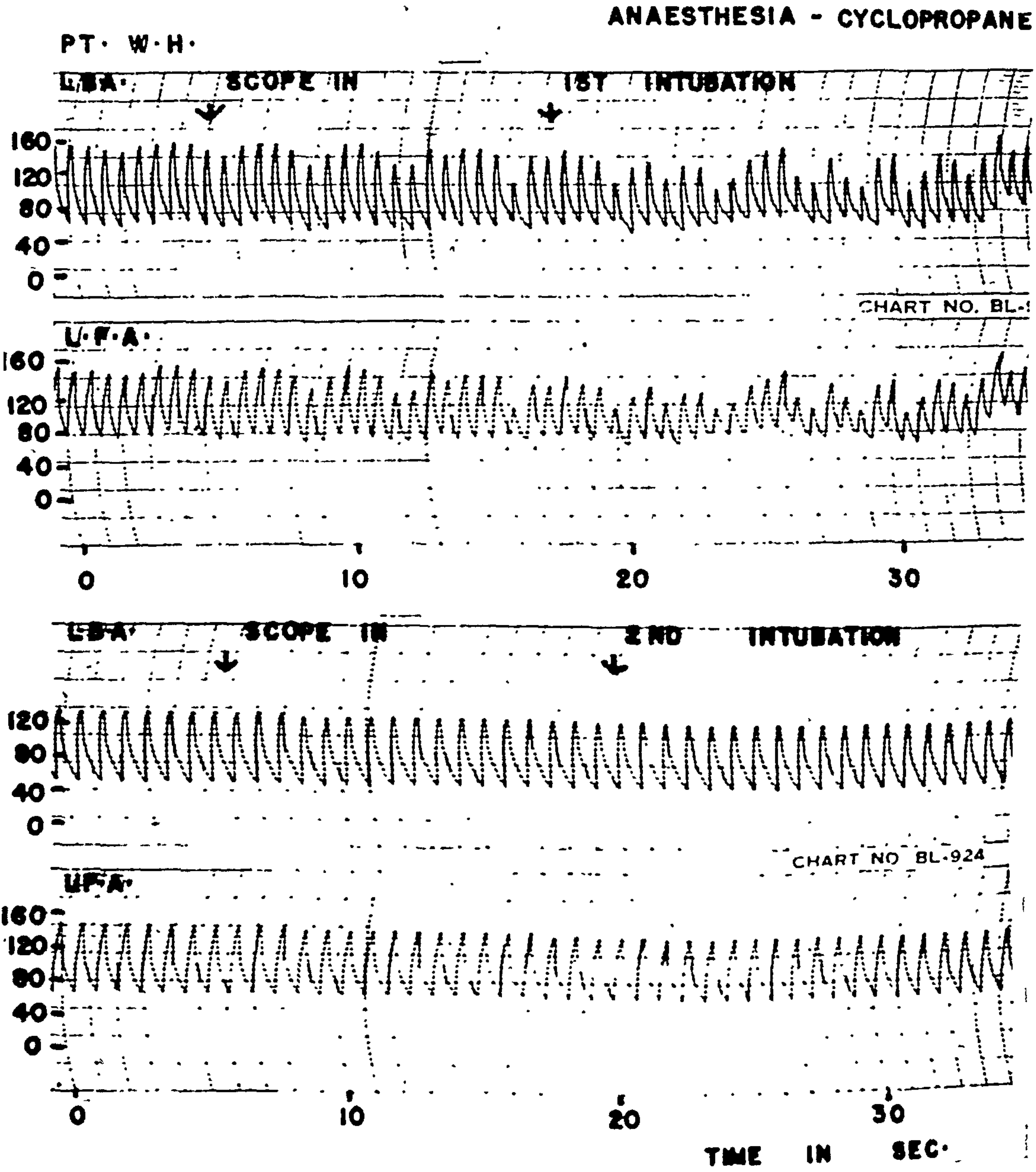

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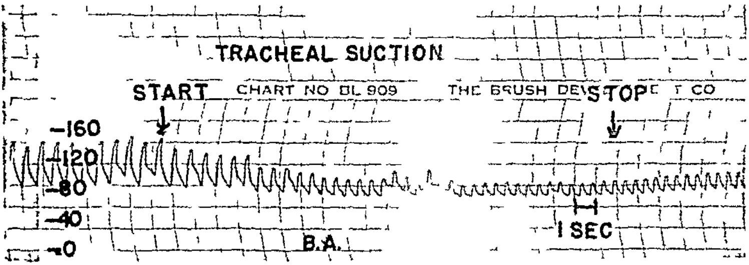

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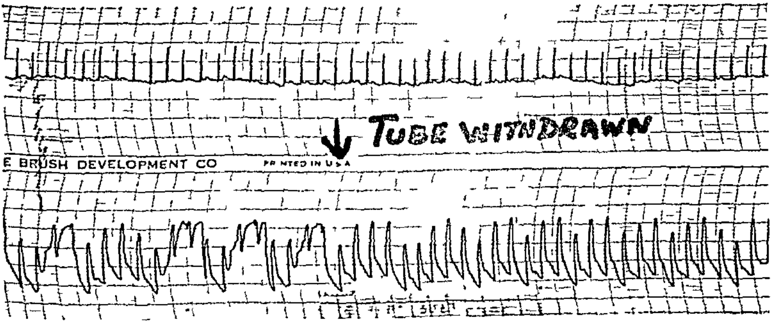

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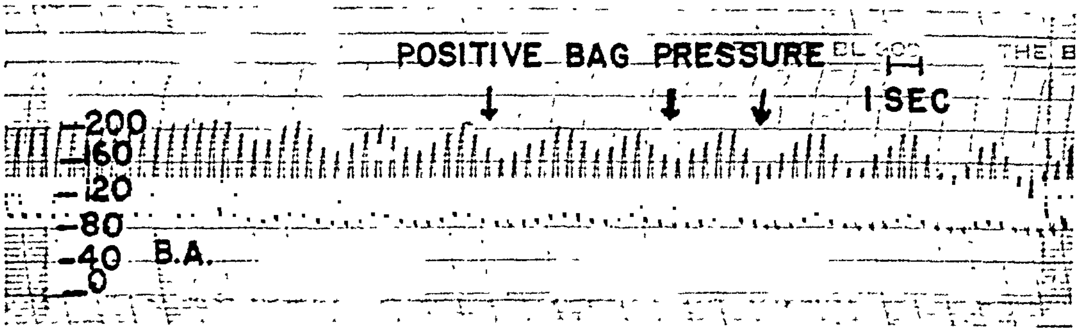

Fig. 5.—Depression of systolic blood pressure during positive pressure respiration by manual compression of the breathing bag.

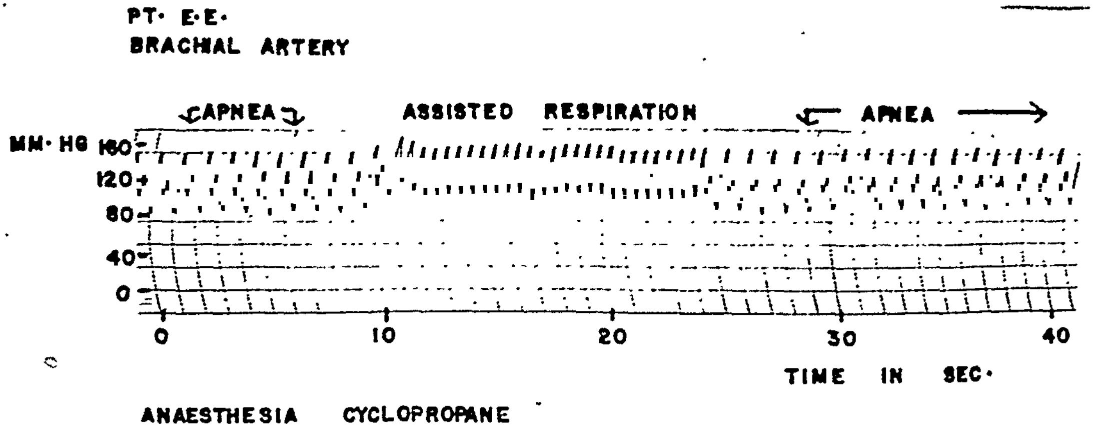

Fig. 6.—Irregular pulse and inadequate blood pressure during apnea, corrected by assisted respiration.

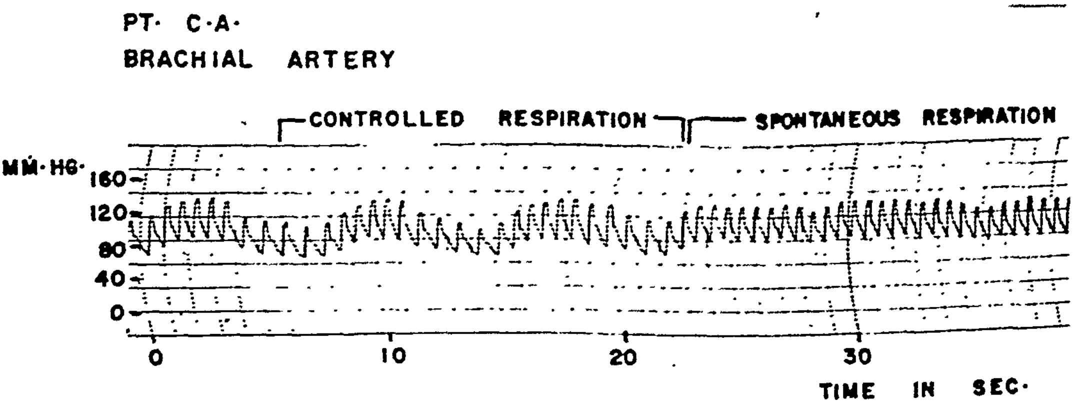

Fig. 7.—Rhythmic depression of blood pressure during positive pressure by manual methods, improved by the return to spontaneous breathing. The chest was closed when this observation was made.

In the patient with severe heart disease, one of the anesthetic goals is the use of light anesthesia. Tolerance to endotracheal manipulations of patients with diminished myocardial reserve during general anesthesia has been an important problem. Sometimes there is a dilemma. A patient with severely weakened myocardium may not tolerate anesthesia of depth sufficient to intubate. He may also respond unfavorably to the effects of intubation in light anesthesia even though topical anesthetics are instilled or nebulized into the airway. He may not do well with muscle relaxants. To solve this problem in patients with serious cardiac disability, it has been our practice to intubate in the conscious state with surface anesthetics. This statement does not infer that other methods are less satisfactory in other people's hands. It has been our experience that intubation prior to the establishment of general anesthesia has been a safe and useful procedure for patients with advanced heart disease.

THE EFFECTS OF ASSISTED AND CONTROLLED BREATHING ON THE CIRCULATION

Precise studies of the effects of positive pressure breathing will be presented by others in this symposium. However, it will be useful to describe a few instances of the circulatory effects of clinically conducted assistance or controlled breathing.

Fig. 5 shows the depression of systolic blood pressure which can occur from modest positive pressure applied to assist spontaneous breathing.

Fig. 6 shows the superiority of assisted breathing to apnea. It is shown to emphasize the need for unremitting assistance to breathing. The rhythm may be broken frequently when manual methods are used to adjust the transfusion, change the light, or record observations on the anesthesia record. These are practical reasons why efforts must be made to achieve physiologically sound mechanical ventilation.

Fig. 7 shows the superiority of spontaneous breathing to controlled breathing when controlled breathing is excessively applied. The chest was closed during this study.

CONCLUSION

Perhaps undue emphasis has been placed on the smaller events of laryngoscopy and endotracheal intubation during thoracic surgery. However, justification for this emphasis exists because it is tacitly assumed in scientific studies or clinical reports in thoracic surgery that there are no potential harmful consequences of intubation. This survey has made it obvious that such an assumption can never be made with security. This discussion will serve its purpose best if endotracheal intubation is performed to provide a minimum lapse between effective breaths and if subsequent anesthesia is conducted in the same manner.

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(For Discussion, see page 474.)

THE CARDIORESPIRATORY DYNAMICS OF CONTROLLED RESPIRATION IN THE OPEN AND CLOSED CHEST

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INTRODUCTION

FACTORS AND MECHANISMS INVOLVED

THE use of rhythmic inflation and deflation of the lungs for resuscitation or controlled respiration during surgery has become well established during the past several decades. Clinical and experimental studies have been performed to delineate the principles and practice of pressure breathing and many mechanical devices have been developed to provide resuscitation, controlled respiration, and respiratory assistance.

However, divergent opinions persist, and it appears important to crystallize the issues by carefully evaluating the basic factors and mechanisms involved in pressure breathing. This would be especially useful if it established the over-all characteristics of a "physiologically ideal" respiratory pattern for both the open chest and the closed chest situation.

Factors Involved.—In order to be complete and adequate such a study must include:

1. Determination of the characteristics of the normal respiratory pattern.
2. Analysis of *all* characteristics of the mechanical respiratory pattern by means of completely controlled experimental and clinical studies. These characteristics are: (a) position of breathing curve—(1) IPP, intermittent positive pressure, (2) PNP, positive negative pressure, (3) INP, intermittent negative pressure, (b) amplitude of the pressure, (c) ratio of inspiratory-expiratory duration, (d) shape of the curve, and (e) rate per minute.
3. Simultaneous evaluation of both the ventilatory and the circulatory dynamics resulting from mechanical respiration.
4. Use of clinically applicable criteria for evaluating all of these factors.

The series of studies reported here was designed to comply with all of these requirements.

Measurements Involved.—The purpose of mechanical respiration is to produce optimal ventilation during surgery or resuscitation, without detriment to the

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circulatory system. The actual performance characteristics of the machines are important only as reflected in their physiologic effects on ventilation and circulation.

Optimal ventilation requires both adequate oxygenation of the blood and elimination of carbon dioxide. Accordingly, the ventilatory criteria we have used throughout these studies are the oxygen saturation and carbon dioxide tension (pCO_2) of arterial blood.

The effects of ventilation on the circulatory system can be measured in many ways. Determination of cardiac output or direct recording of arterial blood pressure provide the best over-all information and are used most often. Direct arterial blood pressure has been used here for several reasons: (1) previous studies have indicated that changes in right ventricular output resulting from pressure breathing are ultimately reflected in left ventricular output and arterial pressure; (2) direct arterial pressure provides a means for continuously monitoring over-all circulatory effects; (3) by means of a direct writer, it is possible to get instantaneous pressure readings; (4) the circulatory effects can be monitored on a beat-to-beat basis; (5) direct arterial pressure is more practical and easily obtained in a controlled series of tests where multiple readings are required over a long period of time, especially in patients undergoing thoracic surgery; and (6) arterial pressure, as a measure of circulatory effects, is used clinically during surgery or resuscitation, and results obtained in such controlled studies can be easily and directly applied to clinical situations.

In all of these studies, both experimental and clinical, blood pressure has been monitored continuously and recorded from a cannula in the femoral artery. Arterial oxygen saturation, pCO_2 and blood pressure have always been recorded simultaneously.

Mechanisms Involved.—Automatic mechanical breathing equipment for rhythmic ventilation of the airway can be classified on the basis of the cycling mechanism: (1) pressure-cycled (pressure-limited); (2) volume-cycled (pressure-limited); (3) time-cycled (pressure-limited).

Pressure cycling devices usually function on a pneumatic basis and depend upon the actuation of a diaphragm or valving mechanism by regulated pressures. They require a tight airway fit for proper cycling.

Volume cycling mechanisms depend on pneumatic or electric activation of a bellows or piston. This delivers a fixed (adjustable) stroke volume. Pressure limits must be set so that the excess volume will not be forced into the lung. A tight connection between the machine and the airway is not required. However, if a tight system is not used, a large volume must be provided in order to compensate for airway leaks.

Time cycling mechanisms usually require electrical activation (or manual timing and manipulation). Such units deliver gas at certain pressure limits on the basis of a mechanism which times the duration of the cycles and phases. A high flow rate unit can be used on either a tight system or one with a large leak.

This classifies only the actuating or cycling mechanisms of mechanical breathing equipment. Most units have additional controls for regulation of pressure, rate, inspiratory expiratory ratio, and sometimes volume.

Fixed volume pumps may be thought to constitute a separate type of cycling mechanism. *However, they represent variations of the volume cycling* category. A true fixed volume pump has an inherent disadvantage in that it is impossible to know the exact volume required by patients of different sizes and ages, as well as at different times during the same procedure if there are changes in the physical characteristics of the lungs. This difficulty can be overcome by using an excess volume and providing a blowoff at certain pressure limits. However, this converts it to a volume cycled (pressure limited) unit. The same is true for the large piston units, such as those used with the uncuffed tracheostomy tube. Here the airway leak provides the pressure blowoff, and it also becomes volume cycled (pressure limited).

FLOW, PRESSURE, AND VOLUME CHARACTERISTICS OF THE NORMAL BREATHING PATTERN

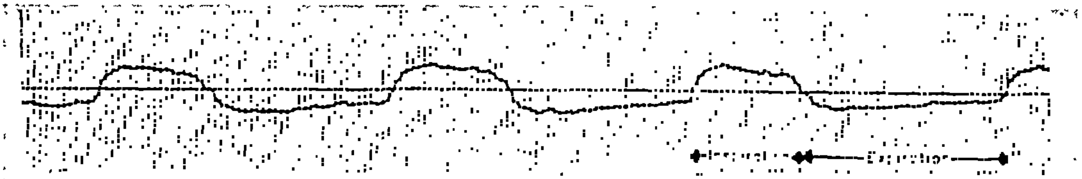
Study of normal breathing curve characteristics should provide insight into the requirements for a mechanical controlled respiration pattern. We have studied three functions of the normal respiratory pattern which lend themselves to measurement. These are (1) flow, (2) pressure, and (3) volume. These were recorded on a group of normal adult males during conscious resting breathing. Each of the test periods was preceded by at least a twenty minute period of complete rest in order to achieve a basal ventilatory state.

Methods.—Air flow was measured by means of a pneumotachograph,[1] which recorded through a differential strain gauge on a photographic recorder. The pneumotachograph provides the most sensitive of the three ventilatory measurements since it involves an open circuit essentially free of the impedance and resistance inherent in the closed circuits used for the other determinations.

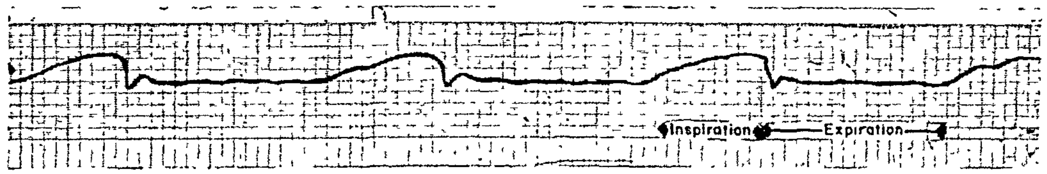
Changes in volume during normal quiet respiration were measured by means of a carefully balanced Waters Conley Respirometer. This is the usual type of clinical equipment used to measure ventilatory pattern and volume. It is designed to measure various components of lung volume and its speed is too slow for eliciting details of curve form. The unit was therefore modified by means of a rotary motor and rheostat to provide a rapid spirogram.[2] This gives greater accuracy and detail of curve form.

There is no standard method for measuring directly the normal airway pressure pattern. With an open system, the pressure changes are instantaneous, and no significant differential can be recorded. Use of a closed system requires a large volume in order to minimize the effects of breathing against the resistance of the closed circuit. For purposes of these tests, we devised a closed system in which the subjects breathed into a 110 gallon system (two 55 gallon drums). Pressure differentials were recorded on the Poly Viso by means of an electromanometer.

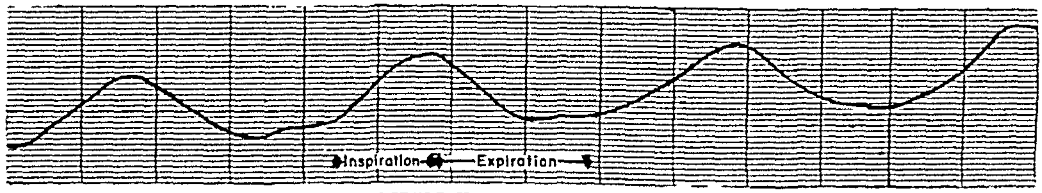
Results and Conclusions.—Typical patterns of air flow, pressure, and volume are shown in Fig. 1. Review of these tracings reveals that the normal inspiratory:expiratory duration ratio ranges between 1:1.5 and 1:2, with a mean of about 1:1.6. Slight variations occur in the same individual from time to time and between members of this group of normals. However, all subjects' tracings were within this range. As mentioned above, the pneumotachographic tracings provide the most accurate reflection of the respiratory phases since there is less resistance and inertia in this recording system.



A. AIR FLOW PATTERN — PNEUMOTACHOGRAM



B. AIR PRESSURE PATTERN — CLOSED CIRCUIT RESERVOIR



C. AIR VOLUME PATTERN — RAPID SPIROGRAM

Fig. 1.—Normal, conscious, resting, breathing patterns in human beings.

The pressure pattern with the closed circuit used here reveals a curve which rises gradually to a short inspiratory plateau, followed by a precipitous expiratory pressure drop to atmospheric, with an expiratory plateau 1½ to 2 times as long as the inspiratory phase. Within the limitations of this closed circuit method, this pattern can be considered as the so-called "normal" pressure breathing curve.

The volume curves provide a similar ratio, but since they are subject to the greatest inertia and resistance, they are least informative as regards curve form.

These ratios of inspiratory:expiratory duration and the "normal" airway pressure curve provide criteria for establishing a "physiologically ideal" pressure breathing pattern.

THE AMPLITUDE OF AIRWAY PRESSURE REQUIRED DURING CONTROLLED RESPIRATION

An important consideration in controlled respiration and resuscitation is the exact amount of positive pressure required to achieve optimal alveolar ventilation without risk of pulmonary damage or other complications In addition, a measure of the physical effects on the lung resulting from various types of controlled breathing might offer insight into the dynamics of this form of ventilation

Pressure volume (PV) diagrams of the lungs and thorax have been shown to provide a measure of the physical status of the respiratory mechanism[3] The factor of airway resistance is eliminated in static pressure volume determinations and, accordingly, this value becomes a measure of the inherent compliance of the system

In order to determine the amplitude of airway pressure required during controlled respiration, we have made two sets of determinations on a group of dogs (1) initial inflation pressure volume diagrams following normal breathing and again at end expiration after periods of various types of controlled respiration (IPP, PNP, and INP), and (2) the end expiratory residual lung volumes following normal breathing and these same types of controlled respiration

Methods—Twenty normal mongrel dogs with an average weight of 30 pounds were anesthetized with intraperitoneal pentobarbital One half of these were used to study the effects of various types of controlled respiration on the pressure volume (PV) diagram of the lungs and thorax at end expiration, the other ten dogs were used to measure the end expiratory residual lung volume after the same types of ventilation

Controlled respiration was administered via a tracheal cannula by means of an Anespirator * This is a pressure cycled unit driven by compressed gas It has adjustable rate and positive and negative pressure controls, and produces a peaked, biphasic airway pressure curve Machines of the pressure *cycled type usually have a constant flow rate, resulting in inspiratory and* expiratory durations being approximately equal The biphasic, peak shaped curve, 1 1 inspiratory expiratory ratio and cycling rate of 12 times per minute were kept constant throughout all phases

An initial normal PV curve was obtained Then each animal had 15-minute periods of controlled respiration with IPP (0 to 22 mm Hg), PNP (11 mm Hg to –11 mm Hg), and INP (0 to –22 mm Hg) The mechanical pressure cycling was always stopped at the end of expiration and an end-expiratory PV curve was obtained immediately after each type of breathing

Previous investigators[3] have used the relaxation PV curve as an index of lung compliance However, for reasons to be discussed later, we have determined the initial inflation PV curve at end expiration in a manner similar to Nims, Conner, and Comroe[4] The relaxation PV curve was recorded and, *immediately following this determination,* a second inflation PV curve was also obtained These measurements were made by using an accurately calibrated hand pump to inject increments of air into a side arm of the tracheal cannula, allowing time for pressure stabilization (usually about 5 seconds), then reading the pressure in the closed lung thorax system directly from a Bourdon gauge attached to the tracheal cannula This pressure was then released, a few seconds allowed for stabilization at atmospheric pressure, and the procedure repeated at the next increment. This was continued until the pressure in the dog's closed lung-thorax system reached 40 mm. Hg.

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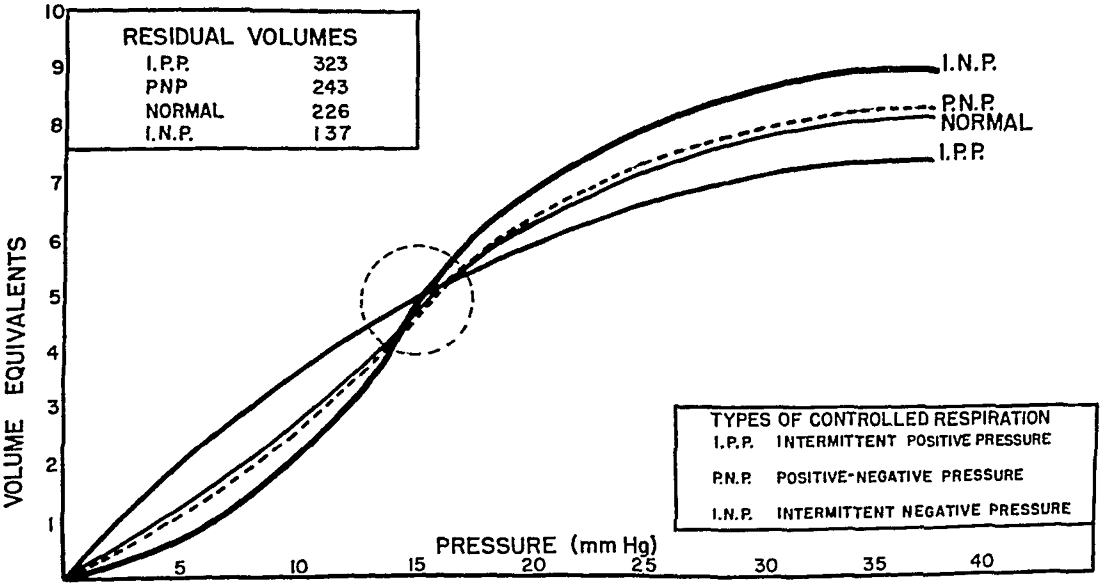
*Provided by E and J Manufacturing Co Burbank Calif

The second group of dogs was prepared as described above. Following normal respiration and after each type of controlled respiration, the end-expiratory residual lung volume was determined by withdrawing air from the closed lung-thorax system until a pressure reading of –40 mm. Hg was achieved. The volume withdrawn at this point was recorded. In most cases, the air could be withdrawn easily at first. Then suddenly the resistance increased greatly and the withdrawal of only a few more cubic centimeters resulted in a large change in pressure. Accordingly, the end points were very sharp.



THE SECOND INFLATION PRESSURE-VOLUME CURVE PARALLELS THE I.P.P. CURVE WITH ALL TYPES OF CONTROLLED RESPIRATION

Fig. 2.—Initial inflation pressure-volume curves following various types of controlled respiration.

Results and Conclusions.—The initial end-expiratory PV curves and residual lung volumes are shown in Fig. 2.

The normal PV curve under these conditions is smoothly S-shaped. It is closely paralleled by the initial inflation PV curve following PNP controlled respiration. IPP results in a flattening of the curve, whereas INP results in accentuation of the S-shape. This means that starting reinflation of the lung after IPP is easier than after INP. This is shown in Fig. 2, where use of the same volume increments for initial reinflation results in less pressure change with IPP than with INP, during the first half of the diagram.

IPP ventilates completely within the inspiratory capacity, and the lungs remain in a partially distended state even at end-expiration. Conversely, at end-expiration after INP breathing, the lung, which has been ventilated entirely within the expiratory reserve volume, is in a more collapsed state with a smaller volume of residual air.

Actual measurement of end-expiratory residual lung volume substantiates this impression. As indicated in Fig. 2, the residual volume is significantly greater following IPP than PNP or normal breathing, and significantly reduced after INP breathing.

However, at approximately 15 mm. Hg pressure on the PV diagram, there is an alteration in this effect resulting in an area where all of the curves intersect and cross. Below this point the curves are divergent; above this point they parallel each other. The explanation for this phenomenon has important significance.

Initial reinflation of the lung requires pressures adequate to overcome a number of forces. These include: (a) the viscoelastic properties of the lungs and thorax; and (b) the surface tension.

The viscoelastic properties of the lungs and thorax are essentially constant at any one point on the PV curve, although they may vary from point to point. However, surface tension is an additional force to be overcome primarily at the beginning of re-expansion of the lungs. At end-expiration, following INP breathing, residual lung volume is markedly diminished. In some areas, alveolar and terminal bronchiolar walls may be in apposition. The pressure required to overcome the increased surface tension is greater than that required to inflate a lung in which alveolar and terminal bronchiolar walls remain at least partially distended, such as after PNP or IPP breathing. This accounts for the greater pressure changes after INP than after IPP at the same volume increments, in the portion of the diagram below 15 mm. Hg.

This is in agreement with the finding of Radford, Lefcoe, and Mead[5] that surface tension tends to hold the walls of alveoli and bronchioles together and make the lung less compliant after complete deflation than after normal expiration.

As surface tension is overcome, inflation progresses to a point where all of the alveoli are inflated. With continued inflation, the physical properties of the INP, PNP, and IPP ventilated lungs approach each other. At the point of uniform alveolar inflation, the PV characteristics of all of these types of lungs are essentially equivalent. This corresponds to the area in which the curves intersect within the broken circle in Fig. 2.

Beyond this point the PV curves parallel each other and are essentially a function of the inherent viscoelastic properties of the lungs and thorax. However, they do remain separated because the IPP lung still has a greater volume at any one point on the curve since its inflation started with a greater initial residual volume.

In our experience, as indicated in Fig. 2, the PV curves do not all cross at a single point, but rather within a certain area. This ranges between 12 and 18 mm. Hg, with the greatest concentration of curve crossing occurring at 15 mm. Hg. According to these measurements, then, approximately 15 mm. Hg positive pressure should be used to accomplish adequate alveolar ventilation with controlled respiration. More detailed studies would probably reveal that IPP breathing requires slightly less inflation pressure than PNP breathing. These findings are similar to those of Lindskog and Bradshaw,[6] who found the threshold pressure for reinflation of experimentally produced atelectasis to be 12 to 16 cm. of water.

Relaxation PV diagrams after all methods of pressure breathing resulted in all of the curves being essentially the same and being located to the left of the initial inflation IPP curve. This is due to hysteresis.[7, 8] The second inflation PV curve similarly showed a shift to the left with all curves being essentially the same and parallel to the initial IPP curve. This is due to elimination of the surface tension factor by the initial inflation to 40 mm. Hg. These two factors are the reasons for using the initial inflation PV curve to determine the effects of the various types of pressure breathing on the physical properties of the lungs and thorax.

The above findings and Fig. 2 relate to the PV characteristics in the closed chest. An additional series of ten dogs were used to study the pressure-volume diagram following IPP and PNP breathing with the unilateral open chest. (INP breathing was not studied since dogs cannot survive this type of breathing with an open chest.)

The open chest IPP and PNP curves are similar in contour and crossing over to the closed chest curves, with the following exceptions: (1) Both curves are shifted somewhat to the left. (2) The two curves are divergent below the crossing-over point and parallel each other above this point, just as in the case of the closed chest. However, throughout their entire extent they are so close together that at no point on the curves are the differences significant. (3) The crossing-over zone occurs between 15 and 17 mm. Hg, with a mean of approximately 16.

Two factors are responsible for these differences: (1) The unilateral open chest partially eliminates the thoracic wall component of compliance, and results in the general shift of the curves to the left. (2) With one chest open, the intrathoracic negativity is lost on that side. This results in collapse of one lung during expiration, even with IPP breathing (if the lung is allowed to come to atmospheric pressure after each inspiration). Accordingly, the end-expiratory position of the lung on the open side is almost the same after either IPP or PNP breathing. This accounts for the fact that the reinflation PV curves show very little difference. Also, since the lung on the open side is more collapsed at end-expiration than in the case of the closed chest, it requires a slightly greater reinflation pressure (16 mm. Hg) to reach the crossing-over point, or zone of uniform alveolar ventilation.

THE EFFECTS OF VARYING THE POSITION AND AMPLITUDE OF THE PRESSURE BREATHING CURVE

As enumerated previously, there are five characteristics of the pressure breathing curve: (1) position; (2) amplitude; (3) inspiratory:expiratory ratio; (4) shape; and (5) rate. In carefully controlled, comparative tests, it is not possible to evaluate all of these simultaneously. Therefore, we have used several series of tests in order to study all characteristics.

In the first series, determinations were made of the cardiorespiratory effects resulting from varying (1) the position of the pressure breathing curve (IPP, PNP, and INP), and (2) the amplitude of the pressure breathing curve (A.—total range of 22 mm. Hg; and B.—total range of 15 mm. Hg). Comparison was also made of the effects of using pure oxygen and compressed air.

The curve form, inspiratory:expiratory ratio and rate were kept constant throughout the series. An Anespirator, as previously described, was used to produce a symmetrical, biphasic, peaked curve with an inspiratory:expiratory ratio of 1:1. A cycling rate of 12 times per minute was used throughout the studies.

Methods.—Two groups of mongrel dogs, having an average weight of 40 pounds, were used. Ten dogs were used for the tests at the 22 mm. Hg range; seven dogs were used for the 15 mm. Hg range. In both groups, all dogs were evaluated at the end of each of a series of 15-minute test periods. These included: (a) an initial control period of normal breathing; (b) closed chest controlled respiration periods with intermittent positive pressure (IPP), alternating positive-negative pressure (PNP), and intermittent negative pressure (INP), using compressed air; (c) a similar closed chest comparative series using pure oxygen; (d) a repeat control period of normal breathing before the chest was opened; (e) open chest controlled respiration during IPP and PNP on compressed air; and (f) a similar open chest series using pure oxygen. In each series, all of the closed chest determinations were performed first, the phases being rotated according to calculated random. A wide unilateral thoracotomy was then performed and the open chest phases were carried out. Intermittent negative pressure (INP) was not used in the open chest series since it was found to result in the death of all dogs.

As the position of the pressure breathing curve was shifted from phase to phase in the first group of dogs, the amplitude remained the same, i.e., IPP = 0 to 22 mm. Hg; PNP = 11 mm. Hg to –11 mm. Hg; and INP = 0 to –22 mm. Hg. In the second group, the amplitude was reduced so that IPP = 0 to 15 mm. Hg; PNP = 7.5 to –7.5 mm. Hg; and INP = 0 to –15 mm. Hg.

Ether anesthesia was used and the controlled respiration was performed via a tracheal cannula. Blood pressure was monitored continuously on a Sanborn Twin Viso from a cannula in the femoral artery. Blood samples for analysis were withdrawn at the end of each 15-minute experimental period from this same cannula via a three-way stopcock. Arterial oxygen saturation was determined spectrophotometrically according to the method of Nahas,[9] and arterial pCO_2 was calculated from the nomogram of Singer and Hastings[10] after determination of pH and CO_2 content.

Results and Conclusions.—In reviewing these results, the important concept is that determination of the most efficient type of controlled respiration requires an integrated appraisal of all of the cardiorespiratory factors studied—blood pressure, oxygen saturation, and carbon dioxide tension. Superiority of a single factor does not establish the method as the best.

The results of all phases with both groups of animals are summarized in Fig. 3. In the closed chest phases at the higher pressure range, positive-negative pressure breathing gave the greatest over-all superiority. Although IPP resulted in the same degree of oxygenation and carbon dioxide elimination, there was a significant difference in the blood pressure response. This resulted from the depressant effect of the high mean airway pressure with the IPP curve.

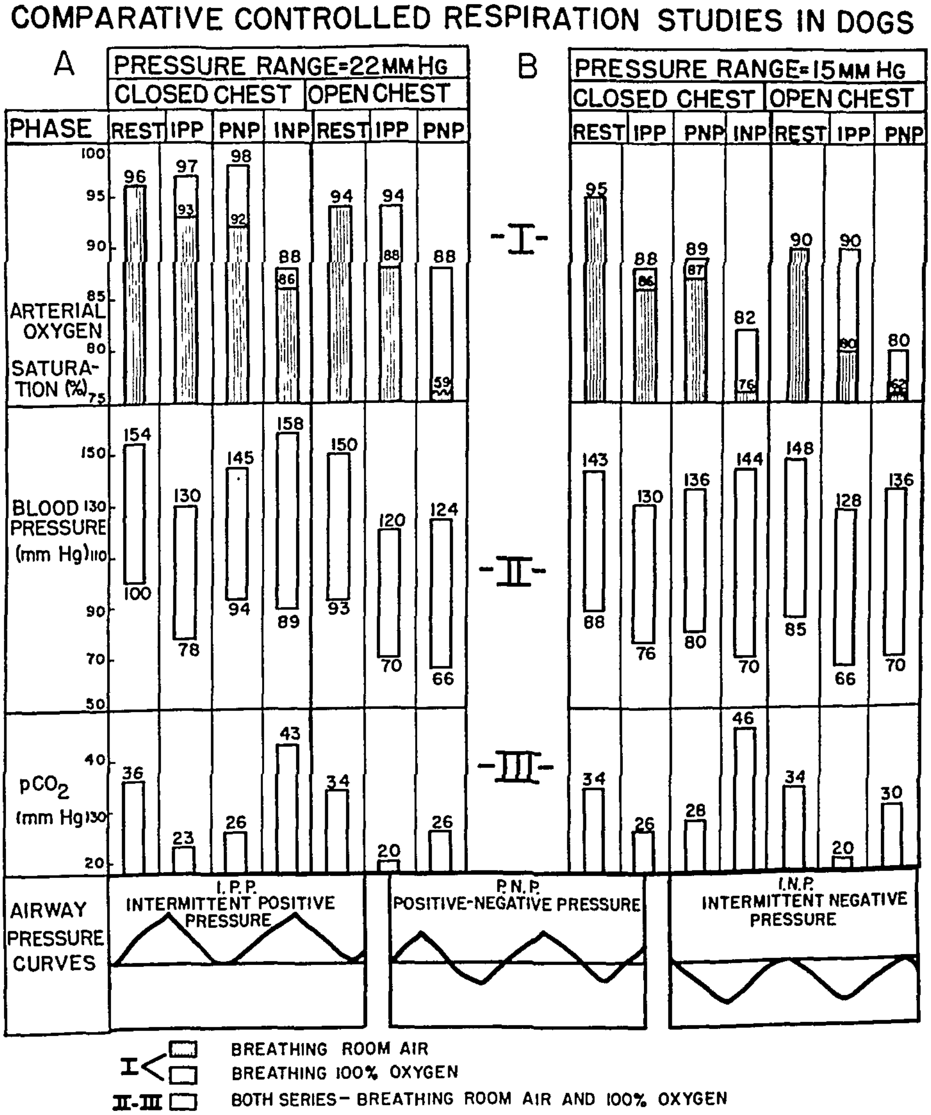


Fig. 3.—Cardiorespiratory effects of varying the position and amplitude of the controlled respiration curve in closed chest and open chest dogs.

The use of INP is not clinically applicable, but was included here for the sake of completeness. The amounts of negativity applied far exceed the usual limits of negative pressure breathing when used in conjunction with positive pressure. However, the use of this amount of negative pressure is informative since it exaggerates the resultant effects. As might be expected, blood pressure was enhanced by the negativity, but the oxygen saturation was severely depressed since the breathing was accomplished entirely within the expiratory reserve volume. This would keep the lungs fluctuating between a collapsed state and a neutral state at all times with no active alveolar inflation.

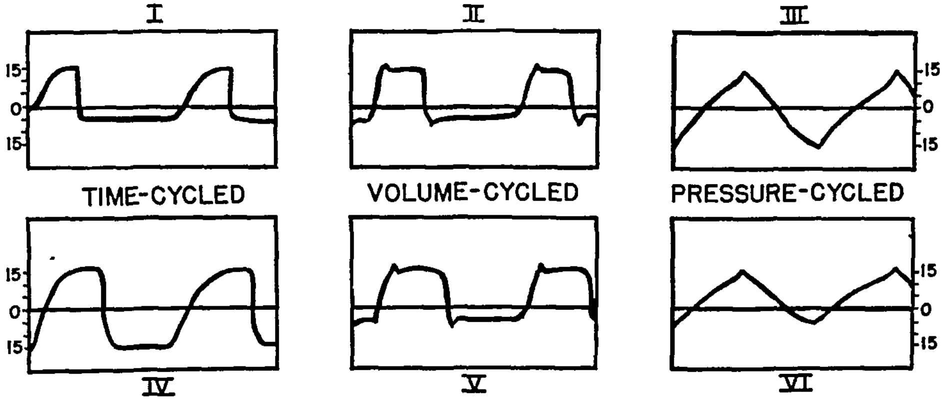
Following INP breathing, the pCO_2 was elevated above the values obtained with the other methods. The reason for this is the same as for the depressed oxygen saturation noted above, inadequate alveolar ventilation. This emphasizes an important concept, namely, carbon dioxide is not "sucked" out of the lungs by negative pressure deflation, but rather it is "flushed" out by adequate alveolar ventilation during positive pressure inflation. Further evidence of this phenomenon is revealed by the comparative arterial oxygen saturation and pCO_2 values during ventilation with compressed air and pure oxygen. Compressed air (20 per cent oxygen) always resulted in lower oxygen saturation values than did pure oxygen with all types of controlled respiration. However, the pCO_2 values were the same with either gas. Here again, elimination of carbon dioxide by any ventilating gas is a function of the alveolar flushing action resulting from the type of ventilation used, whereas the oxygen saturation is directly related to the concentration of oxygen in the ventilating medium as well as the adequacy of alveolar ventilation.

During open thoracotomy, blood pressure and oxygen saturation were always lower with any type of ventilation than with the same type in the closed chest. With the chest open, IPP breathing provided near normal oxygen saturation and the greatest elimination of carbon dioxide. Although blood pressure was slightly lower with IPP than with PNP in the open chest, the difference was not significant. The use of –11 mm. Hg negative pressure here resulted in profound depression of the arterial oxygen saturation (especially with the use of compressed air). High negativity with PNP open chest ventilation results not only in collapse of the lung on the opened side, but the mediastinum is displaced to the unopened side, resulting in some pulmonary collapse on the unopened side. This effect is more marked in the dog than in man because of the thin, unstable nature of the canine mediastinum; it is also more marked here than with the usual amounts of negativity used clinically.

For the same reasons, INP cannot be used at all during open thoracotomy in dogs. When attempted it universally results in the rapid death of the animals. Even when PNP is used on open chest dogs, the shape of the pressure breathing curve is altered because of the minimal mediastinal support. Following the positive pressure phase, the negative phase is abrupt and shortened because of rapid collapse of both lungs.

Review of Fig. 3 reveals that essentially the same relative findings resulted in the group of dogs tested at the lower pressure range (15 mm. Hg). PNP again was superior in the closed chest phases, and IPP was equally effective with the chest opened. The arterial oxygen saturation and the carbon dioxide elimination were somewhat less than in the previous group, but this is a logical consequence of the diminished amplitude of positive pressure. Blood pressure differences were also relatively less pronounced because of the lower mean airway pressure.

Throughout all phases (except INP in the closed chest) the pCO_2 levels were maintained well below normal. This is consistent with the observation that adequate IPP or PNP controlled respiration usually results in hyperventilation apnea with respiratory alkalosis.



	I	II	III	IV	V	VI
ARTERIAL OXYGEN SATURATION (%)	95	94	93	93	92	93
pCO_2 (mm Hg)	19	20	18	20	21	20
BLOOD PRESSURE (mm Hg)	153/102	142/100	139/98	137/95	129/88	118/80
RATIO INSP/EXP	1:2	1:2	1:1	1:1	1:1	1:1
MEAN AIRWAY PRESSURE (mmHg)	0	0+	0	0	+5	+5
RANGES	+15:-5	+15:-5	+15:-15	+15:-15	+15:-5	+15:-5

Fig. 4.—Cardiorespiratory effects of varying the curve shape and inspiratory:expiratory ratio in closed chest dogs.

THE EFFECTS OF VARYING THE SHAPE AND INSPIRATORY:EXPIRATORY RATIO OF THE PRESSURE BREATHING CURVE

In the previous studies we determined the effects of varying the position (IPP, PNP, INP) and amplitude (22 mm. Hg range, and 15 mm. Hg range) of the pressure breathing curve. Remaining characteristics to be evaluated include the curve shape and the ratio of inspiratory:expiratory duration. A carefully controlled, comparative study of these factors was performed on a group of closed chest mongrel dogs and is reported here.

Three distinctive curve shapes were evaluated (Fig. 4). The curve shape was dependent upon the automatic cycling mechanism of the machines used. All of these units were equipped with adjustable pressure controls, but the actual cycling mechanisms were of the types previously described, namely: (1) pressure-cycled; (2) volume-cycled; and (3) time-cycled.

The pressure-cycled unit (Anespirator) has a constant flow rate and builds up pressure differentials that activate a diaphragm mechanism. This produces a peaked, biphasic curve with almost straight-line slopes having approximately equivalent inspiratory and expiratory duration and sharp maximum peak pressures (Types III and VI, Fig. 4).

The volume-cycled unit (Jefferson Ventilator*) ventilates by means of a bellows mechanism. Adjustable pressure-limiting valves are used to divert the excess volume from the bellows. The volume is large and the inspiratory and expiratory strokes are rapid. Since the volume of the bellows exceeds the intrapulmonary volume required at the pressure settings used, the inspiratory and expiratory pressures are reached rapidly and the peaks of inspiration and expiration are cut off, resulting in flat inspiratory and expiratory plateaus and a square curve form (Types II and V). Rate and inspiratory:expiratory ratio are adjustable.

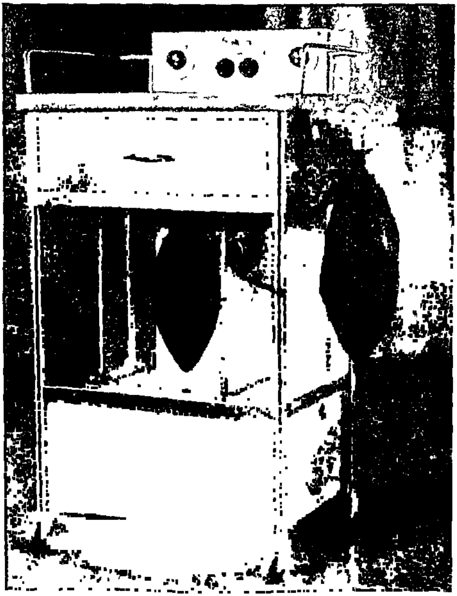


Fig. 5.—Time-cycled controlled respiration and resuscitation unit for producing "physiologically ideal" airway pressure curve characteristics.

The normal closed circuit pressure pattern which we recorded earlier (Fig. 1) has a gradual pressure rise to a short inspiratory plateau followed by an abrupt fall during expiration to a prolonged expiratory plateau. The ratio of inspiratory duration to expiratory duration was between 1:1.5 and 1:2.

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*Air-Shields, Inc., Hatboro, Pa.

We desired to evaluate this shape of curve also. An opportunity to do so was provided by a time-cycled, blower-type of controlled respiration unit* (Fig. 5). Independently adjustable controls are provided for rate (5 to 40 per minute), positive pressure (10 to 30 mm. Hg), negative pressure (0 to -10 mm. Hg) and ratio of inspiration to expiration (1:1, 1:2, and 1:3). The actual cycling is accomplished on the basis of the timing of the inspiratory: expiratory ratios. The unit has a high instantaneous flow rate (150 to 200 liters per minute) and produces a curve form (Types I and IV) similar to the so-called "normal" pressure breathing pattern observed earlier.

Methods.—These studies were performed on ten mongrel dogs averaging 40 pounds in weight. The dogs were prepared and determinations were made as described previously. After initial control readings were taken, each dog had all six variations of curve form shown in Fig. 4 performed for 15-minute periods each. Blood pressure, arterial oxygen saturation, and pCO_2 were measured at that time. The curve forms were rotated in their order of performance.

This protocol provides a critical comparison not only of three curve shapes and two inspiratory:expiratory ratios (1:1 and 1:2) produced by three types of cycling mechanisms, but also incorporates a cross comparison of two pressure ranges (15 to -5 mm. Hg, and 15 to -15 mm. Hg) and two mean mask pressures (zero and +5 mm. Hg). Having previously considered the issues of curve position and amplitude, this series of tests should provide the additional data required to evolve the physiologically ideal controlled respiration curve characteristics.

Results and Conclusions.—Fig. 4 reveals that all of these curve shapes and inspiratory-expiratory ratios provide essentially the same degree of oxygenation and carbon dioxide elimination. This is a reflection of the adequacy of alveolar ventilation resulting from curves with positive pressure phases of 15 mm. Hg. The oxygen saturation of Curves I and II is slightly, but not significantly, higher than observed with the other curves.

All curves have an inspiratory:expiratory ratio of 1:1, except Curves I and II, which have a 1:2 ratio. The two curves (V and VI) with a positive mean airway pressure (+5 mm. Hg) had a blood pressure reading significantly below the other curves, which had mean airway pressures of zero. The effect of an elevated airway pressure in reducing cardiac output and arterial pressure has been well documented by previous investigators.[11-17] It is important to note that these blood pressure effects resulting from elevation of the mean airway pressure occurred in essentially normal animals. The studies of Maloney and associates[12] and Hubay and co-workers[18] have indicated that the circulatory effects of pressure breathing are accentuated in the presence of hypovolemia or shock.

However, in Curves I through IV, where the mean airway pressure was maintained at zero, marked differences in blood pressure still occurred. Curves III and IV showed greater circulatory depression than Curves I and II. This could not have resulted from the greater negativity used in these instances since our previous studies (Part III) and Whittenberger's review of the subject[7] have indicated that negativity enhances circulatory effects in the closed chest. Curves I and IV have the same shape, so curve form per se could not be the cause of this difference in arterial blood pressure. The remaining difference between Curves I and II and Curves III and IV is the ratio of inspiratory:expiratory duration. The former have a 1:2 ratio and the latter a 1:1 ratio. At any one pulse rate, the curve with a 1:1 ratio has a greater number of heartbeats during the positive pressure than a curve with a 1:2 ratio. This factor accounts for the circulatory superiority of Curves I and II.

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*Developed by E and J Manufacturing Co., Burbank, Calif.

Motley and co-workers[13] emphasized this point in their careful studies of intermittent positive pressure breathing. They showed that positive airway pressure during inspiration results in decreased net filling pressure and decreased cardiac output from the right heart. A rapid fall in pressure during expiration results in an increase in net filling pressure leading to an increase in cardiac output. With the expiratory duration exceeding the inspiratory, the heart is able to compensate for the impairment due to pressure breathing.

During inspiration the left heart briefly increases its output (for 3 to 5 beats) due to increased filling by blood squeezed out of the lungs. However, after a short interval the effect of reduction in right heart output is transmitted to the left heart, resulting in a fall in left heart output and a reduction in arterial pulse pressure. Therefore, it is important to provide a longer expiratory phase. This permits more heartbeats during expiration, which allows the heart to compensate for the decreased output occurring during positive pressure inspiration.

Werko's studies[19] on the effects of positive pressure breathing on the circulation in man further emphasize the importance of the beat-to-beat effect and the advantage of a rapid fall in expiratory pressure with an expiratory phase exceeding the inspiratory in duration.

Although Curves I and II both have an inspiratory:expiratory ratio of 1:2, the same amplitude of pressure change, and the same mean airway pressure, the former curve reveals less impairment of blood pressure. This effect, then, must be related to the curve form. A beat-to-beat analysis again provides the explanation. With Curve II, all of the heartbeats during the inspiratory phase are during maximum pressure, due to the square curve form. During inspiration with Curve I, maximum pressure is exerted only during the terminal inspiratory plateau portion of this phase, thereby resulting in less detriment to circulation.

This beat-to-beat blood pressure effect can easily be demonstrated by monitoring the continuous simultaneous record of arterial blood pressure and controlled respiration breathing curve. Fig. 6 illustrates that when a 1:2 ratio is used, the beat-to-beat effect on blood pressure is a rise during two-thirds of the respiratory cycle and a fall during one-third of the cycle. In the final analysis, Curve I most nearly approaches the "physiologically ideal" airway pressure curve. Such a curve must have an adequate inspiratory plateau to provide uniform alveolar ventilation for arterial oxygen satur and carbon dioxide elimination. However, the inspiratory positive pressure must be sustained only long enough for optimal ventilatory effects, with minimal detriment to the circulatory system.

The 1:2 inspiratory:expiratory ratio is usually best. However, there are instances where special circumstances dictate the use of a different ratio. In the lung which has decreased compliance (pulmonary edema, fibrosis, etc.), obstruction (secretions), or increased resistance (bronchospasm) it becomes necessary to reduce the flow rate, increase the pressure, or augment the inspiratory duration, or use a combination of these techniques. In such a situation it may prove beneficial to use a 1:1 ratio of inspiratory:expiratory duration, at least temporarily.

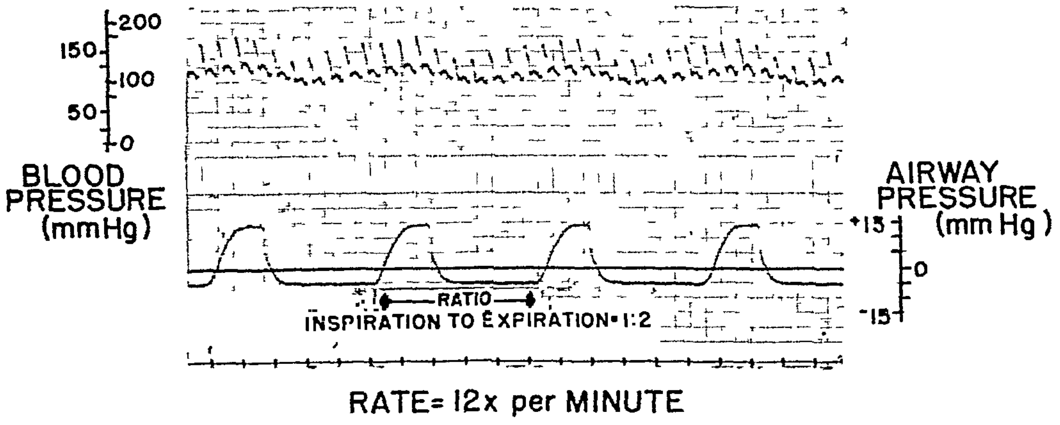

Fig. 6.—Beat-to-beat circulatory effects with "physiologically ideal" PNP breathing curve.

In the asthmatic or emphysematous chest, expiratory flow is the ventilatory problem. In addition to slowing the rate, in such instances it may also be necessary to use a 1:3 inspiratory:expiratory ratio.

CLINICAL APPLICATION OF VARYING THE CHARACTERISTICS OF THE PRESSURE BREATHING CURVE IN CLOSED AND OPEN CHEST HUMAN BEINGS

The previous portions of this work have detailed, controlled, comparative studies of the effects of the various characteristics of the pressure breathing curve on the cardiorespiratory dynamics of closed and open chest dogs. On a practical basis, it becomes important to determine the applicability of these findings to human beings.

Two series of studies were performed on human beings:

1. *Open chest:* Twelve patients were studied during exploratory thoracotomy for resection of various types of pulmonary pathology, including tuberculosis, bronchiectasis, carcinoma, and granuloma. In each case, as soon as the chest was opened, the extent and nature of the pathology were determined, but the resection per se was not performed until after the completion of four ten-minute test periods with various forms of controlled respiration. In this way, each patient represented a completely controlled series, since the effects of extraneous factors, such as surgical manipulation, hemorrhage, pul-

monary compression, etc., were eliminated and the observed cardiorespiratory effects reflected only the dynamics resulting from the controlled respiration.

2. *Closed chest:* The other group consisted of twelve normal adult male student volunteers in whom controlled respiration studies under anesthesia were performed with the chest closed.

Methods.—After being anesthetized and intubated with a cuffed endotracheal tube, each subject and patient had an indwelling polyethylene catheter placed in the femoral artery. By means of a three-way stopcock, isotonic saline was infused to keep the catheter open, blood pressures were recorded on a Sanborn Poly-Viso via a Statham strain gauge and amplifier, and blood samples were withdrawn for determination of pCO_2.

Arterial oxygen saturation was determined by means of a Wood direct reading ear oximeter[20] converted to record on a direct writing potentiometer.[21] The nomogram of Singer and Hastings[10] was used to calculate pCO_2, as noted previously.

During the closed chest studies, initial control determinations were first made on the anesthetized subjects. Then each was evaluated during four ten-minute test periods of controlled respiration. These consisted of: (1) IPP breathing at 0 to 15 mm. Hg by means of the pressure-cycled Anespirator, which gives peaked, biphasic curves and a 1:1 ratio of inspiration to expiration; (2) IPP breathing at 0 to 15 mm. Hg by means of the E and J time-cycled controlled respiration unit, which provides a physiologically ideal shaped curve and a 1:2 ratio; (3) PNP breathing at 15 mm. Hg to -5 mm. Hg with the Anespirator; and (4) PNP breathing at 15 mm. Hg to -5 mm. Hg with the E and J controlled respiration unit. The methods were rotated randomly in their order of performance.

The patients undergoing thoracotomy had a set of closed chest control determinations made during surgery before the pleura was opened. Open chest control determinations were made after the lung had been freed up and the nature and extent of the pathology determined. Each patient was then evaluated at the end of the same four test periods of controlled respiration as described for the closed chest human beings. The regular closed circuit of the anesthesia machine is used for these controlled respiration units. The pressure variations are exerted on an anesthesia breathing bag suspended in an airtight plastic globe.

Results and Conclusions.—In both the closed and open chest human series, the over-all findings were in agreement with those observed on dogs in the preceding sections. Fig. 7 reveals that in the closed chest better results are obtained for blood pressure, oxygen saturation, and pCO_2 with both types of curves during PNP breathing than with these same curves during IPP breathing. However, the ideal PNP controlled respiration curve provides the optimal arterial oxygenation, carbon dioxide elimination, and blood pressure elevation in closed chest cases.

In the open chest patients, the ideal IPP controlled respiration curve provided the most satisfactory over-all effects as regards oxygen saturation, carbon dioxide elimination, and maintenance of blood pressure. Both IPP and carbon dioxide elimination. However, the inspiratory positive pressure must be sustained only long enough for optimal ventilatory effects, with minimal detriment to the circulatory system.

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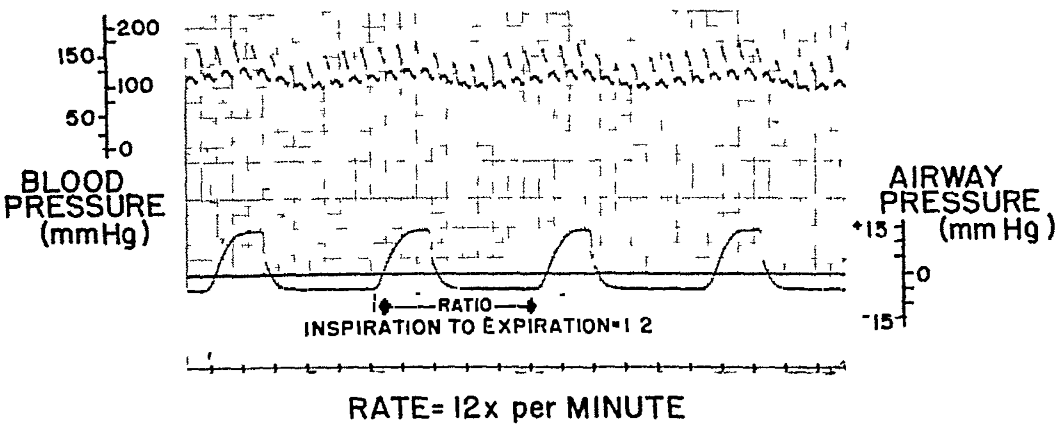

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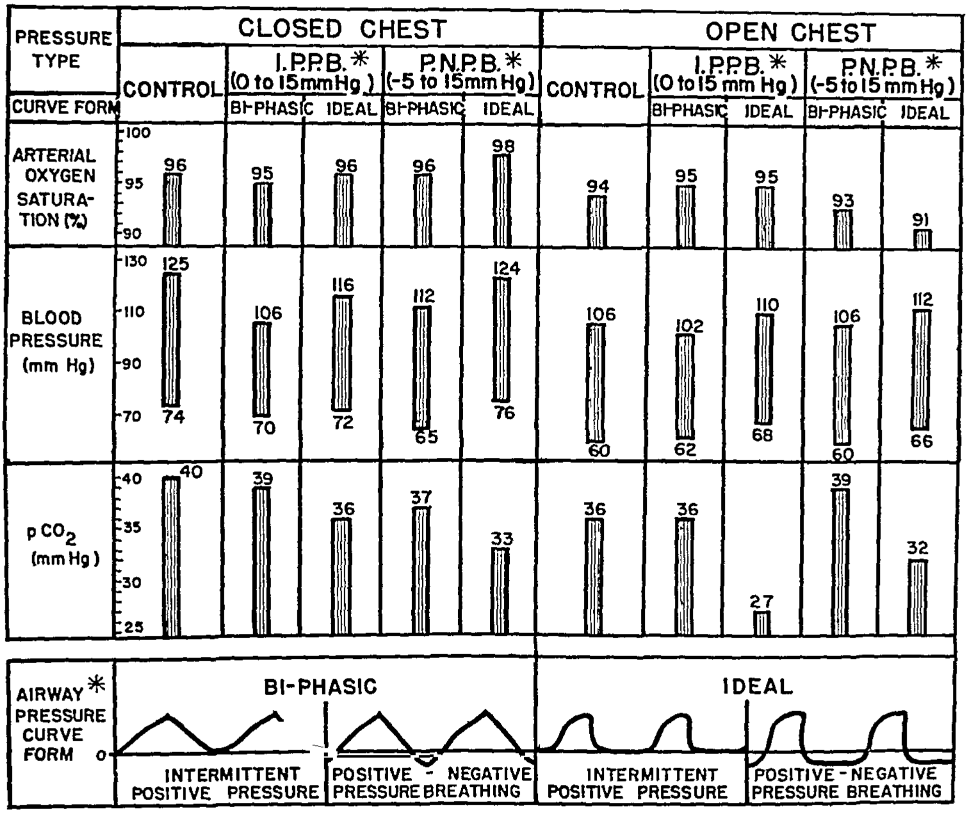

Fig. 7.—Cardiorespiratory effects of controlled respiration in open and closed chest human beings.

Throughout these human studies the results show a consistent trend, i.e., PNP breathing is superior in the closed chest, the use of a negative phase does not serve any significantly useful purpose in the open chest, and the curve with the ideal characteristics produces superior cardiorespiratory effects with either IPP or PNP breathing. Sometimes the actual differences between the methods are not great. However, in all instances, they corroborate the previous findings in the dog studies. Furthermore, all of these closed chest and open chest human studies were carried out under carefully controlled conditions with the subjects and patients maintained in an essentially normal state. As previously pointed out, these cardiorespiratory effects are known to be accentuated by shock, hemorrhage, cardiovascular instability, etc.

Rate: Detailed controlled studies of cycling rate were not performed in any of these tests. However, we found that a near-normal cycling rate of 12 times per minute provides normal oxygenation and carbon dioxide elimination in most adult cases. Slowing the rate below this level can result in ventilatory insufficiency. Significantly faster rates do not usually aid ventilation or circulation and serve further to eliminate carbon dioxide, which is already reduced to an alkalotic level by a rate of 12 per minute. If rate becomes too fast, the inspiratory phase can be shortened to the point where inadequate alveolar ventilation results.

No controlled respiration studies were carried out on infants or children. Goddard and associates[72] have shown that newborn resuscitation requires special consideration of pressure and time relationships. However, for infants and children beyond this neonatal stage, the same curve form and characteristics should be used as with adults, with the exception of the rate. According to the nomogram of Radford,[73] infant respiratory rates range between 30 and 50 and children between 18 and 30. For controlled respiration, a rate approaching these normal levels should be used.

Manual controlled respiration. Controlled respiration in the form of manual compression of the anesthesia bag is still used more frequently in most hospitals than automatic controlled respiration. The principles elucidated here regarding the cardiorespiratory effects of the curve form and characteristics apply equally to this form of controlled respiration. It is not possible to administer a negative phase with the usual anesthesia machine. However, intermittent positive pressure can be administered by means of a curve which is as physiologically ideal as that obtained with an automatic device.

Fig. 8, *A*, shows such a manual controlled respiration pattern and, in the table below, illustrates the minimally depressant effect it has on blood pressure. Fig. 8, *B*, *C*, and *D* reveals the deleterious circulatory effects which result from increasing the airway pressure by incomplete release of the anesthesia bag, sustaining the inspiratory phase too long, and too rapid cycling.

A physiologically ideal breathing curve should be the goal in resuscitation and controlled respiration by either manual or mechanical means.

Hyperventilation alkalosis. The hazard of respiratory acidosis during thoracic surgery has been stressed by Beecher and Murphy.[24] It has been re-emphasized by others and shown to be present in depressed states and resuscitative conditions. Dripps and Severinghaus[75] have recently reviewed the effects of hypercarbia, and Brown, Miller, and co-workers[76, 77] have studied the serious results of rapid carbon dioxide elimination.

However, as revealed in all of our studies, the use of automatic controlled respiration prevents respiratory acidosis, except in the case of INP (Fig. 3), which is not used clinically. All methods of mechanical breathing which were considered adequate resulted in hyperventilation alkalosis, as indicated by the depressed pCO_2 values. This raises the question of whether the alkalosis resulting from passive hyperventilation can be deleterious.

Active hyperventilation requires energy expenditure and results in tetany and loss of consciousness. However, there has never been well substantiated evidence that passive hyperventilation alkalosis, such as that resulting from use of tank respirators or controlled respiration units, is dangerous or deleterious. Morch, Saxton, and Gish[78] have reported keeping patients in hyperventilation alkalosis for long periods of time without any apparent difficulty.

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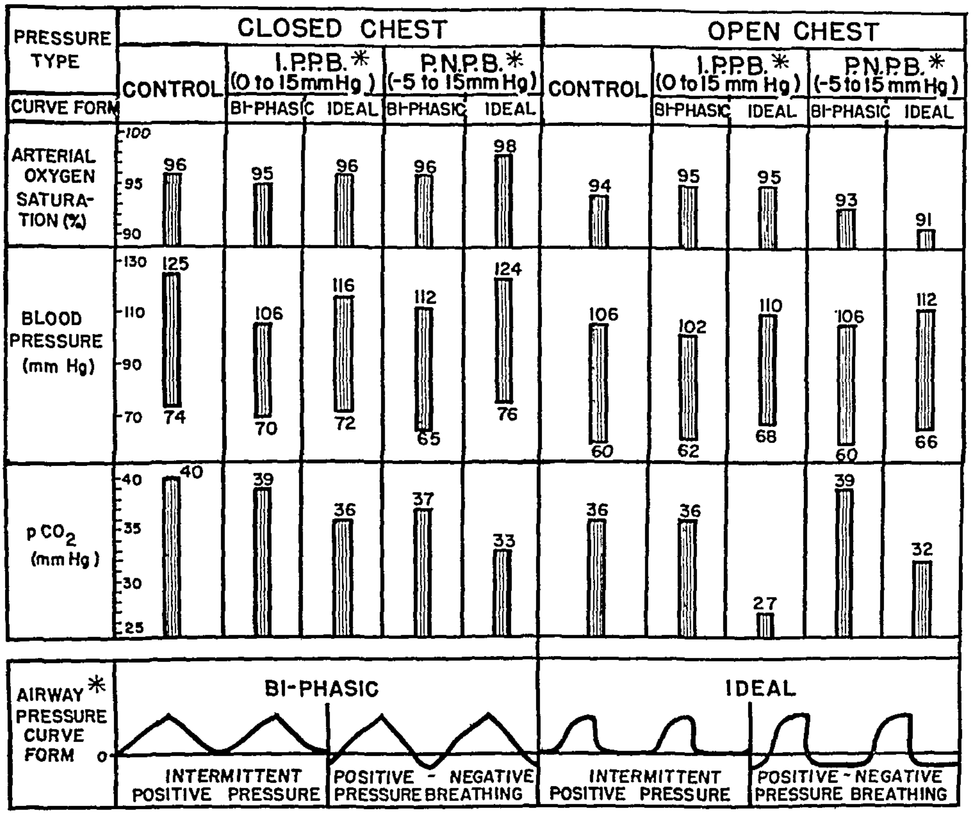

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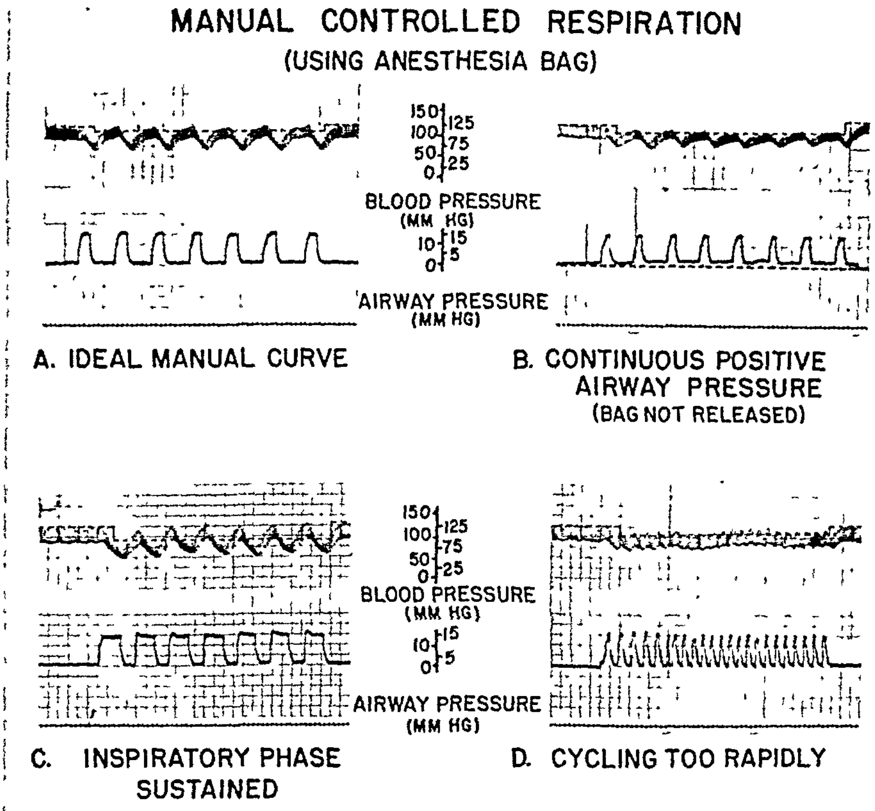
However, Crane, Affeldt, Austin, and Bower[29] have come to question the desirability of this condition on the basis of their findings in poliomyelitis patients.

For the present, it is generally assumed that passive hyperventilation alkalosis does not have serious consequences, at least when only used for limited periods during controlled respiration or resuscitation.



CURVE TYPE	MEAN SYSTOLIC BLOOD PRESSURE (MM HG)		
	DURING NORMAL RESPIRATION	DURING CONTROLLED RESPIRATION	DIFFERENCE
A	117	110	7
B	127	106	21
C	123	94	29
D	126	105	21

Fig. 8.—Comparison of ideal and other breathing curves obtained by manual controlled respiration by means of anesthesia breathing bag.

Negative pressure phase in open chest: Divergent opinions persist regarding the usefulness of a negative pressure phase in open chest controlled respiration. Gibbon and Haupt,[30] Nealon and associates,[31] and Allbritten and co-workers[32] advocate a negative expiratory phase in the open chest. They find that negative pressure during deflation lowers mean airway pressure, although they use an inspiratory:expiratory ratio of 1:1, which raises mean airway pressure.

Bjork, Engstrom and associates[33] use a volume cycled positive negative pressure device for controlled respiration during thoracic surgery, but they state, "In the open thorax, the effect on the circulation of a negative phase and a low mean pressure may be less "

Hubay, Ankeney, and co workers[18, 34] have used a bristle flowmeter to measure the beat to beat effect of IPP and PNP breathing They find that in the open chest " the interposition of a negative phase between positive pressure lung inflations does not benefit the circulation significantly " This is in agreement with our findings in animals and human beings

Waltz, Hubay, Ankeney, and Merrill[35] have studied the pulmonary histopathology following positive and negative pressure respiration They found that negative pressure in the open chest results in complete collapse of bronchioles at lower pressures Accordingly, they recommend that effective pulmonary ventilation can be accomplished with minimal lung damage at a positive pressure range of +15 to +20 cm of water and a negative pressure range of –5 cm of water The collapse of terminal bronchioles with negative pressure probably accounts for the high pCO_2 observed in our dogs subjected to INP of zero to –22 mm Hg This collapse tends to trap air in the alveoli and prevent adequate flushing out As mentioned previously, carbon dioxide must be flushed out of the alveoli rather than being sucked out

Although our results similarly indicate that a negative expiratory phase serves no significant purpose in the open chest, we recognize that there are certain situations in which a small amount of negativity may be advisable (1) In emphysematous lungs, negative pressure may be helpful in assisting deflation (2) Where there is expiratory resistance due to a narrow endotracheal tube, a negative expiratory phase may prevent overdistention (3) Use of a very rapid cycling rate may allow insufficient time for adequate deflation without the addition of a negative phase (4) Overdistention from any cause may hinder the surgeon and necessitate negative pressure deflation to reduce obscuration of the field

If negativity is used, it need not exceed –5 mm Hg if the curve shape and inspiratory expiratory ratio are physiologic Excessive negativity promotes complete collapse of the lung in the open chest This lung may then constitute a venoarterial shunt,[illegible] and it also requires more than the usual pressures for reinflation

SUMMARY AND CONCLUSIONS

1 Carefully controlled, comparative tests, performed on both open and closed chest dogs and human beings, have established the characteristics of the "physiologically ideal" controlled respiration curve (Fig 6) on the basis of arterial oxygen saturation, pCO_2 and blood pressure determinations These are

Shape The curve should have a gradual pressure rise to a short inspiratory plateau followed by an abrupt expiratory fall to a longer expiratory plateau

Position Positive negative pressure (PNP) provides over all superior controlled respiration in the closed chest This is due to the effect of the ne phase in lowering mean airway pressure so that the delet inspiratory positive pressure on cardiac refill (and ultimately on cardiac output and arterial blood pressure) can be compensated for during the expiratory phase. With the open chest, the use of a negative pressure phase provides no significant circulatory benefit and, if excessive, may be deleterious as regards ventilation. IPP breathing is recommended in the open chest, except under special circumstances which have been detailed.

Amplitude: Positive pressure of approximately 15 mm. Hg is required to provide uniform alveolar ventilation. This influences both oxygenation and carbon dioxide elimination. Negative pressure, when used, serves only to lower the mean airway pressure in the closed chest, thereby avoiding circulatory embarrassment. With the unilaterally open chest the lung can collapse after each inspiratory phase, due to loss of intrathoracic negativity. Pressure-volume studies indicate that slightly more pressure is usually required for adequate reinflation in the open chest than in the closed chest. With a properly shaped curve, a low mean airway pressure can be attained even with these positive pressure phases. The usual PNP range for the closed chest should be approximately 15 mm. Hg to -5 mm. Hg, and the usual IPP range for the open chest should be approximately zero to 16 mm. Hg.

Inspiratory:expiratory ratio: For both PNP and IPP in the open or closed chest, a 1:2 ratio of inspiration to expiration provides optimal ventilation and is least deleterious to the circulation. The duration of inspiratory positive pressure influences the blood pressure on the basis of the mean airway pressure and the number of heartbeats during the positive phase. Under certain conditions, which we have detailed, it may be advantageous to vary this ratio.

Rate: A controlled respiration rate of 12 per minute was found to be adequate for most adults. For infants and children the rate should be increased and varied according to their age and size.

2. This curve form compares favorably with the so-called normal airway pressure pattern obtained by use of a large closed circuit reservoir.

3. This curve form and characteristics can be produced by a time-cycled controlled respiration and resuscitation unit. Such a device was used for these studies.

4. This curve form and characteristics can also be produced by manual compression of the anesthesia bag (IPPB only).

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(For Discussion, see page 474)

THE SIGNIFICANCE OF THE LUNG-THORAX COMPLIANCE IN VENTILATION DURING THORACIC SURGERY

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ADEQUATE pulmonary ventilation during anesthesia is essential for maximum protection of the patient during surgical operations. Previous studies of arterial pH, pO_2, and pCO_2 during general anesthesia for surgical operations have shown that the usual methods of providing ventilation fail to maintain a consistently normal pCO_2 level with consequent development of respiratory acidosis.[1-8] In some cases, the arterial pCO_2 was elevated two or three times above the normal level. Inadequate ventilation was found to occur more often during intrathoracic operations, especially during pneumonectomy. It has been found that the effective ventilation was often decreased during intrathoracic operations and a considerable increase in minute volume was required to provide adequate effective ventilation.[4, 7, 9] Adding assistance to the deflation phase of respiration, as well as to the inflation phase, provided consistently adequate ventilation without excessive elevation of airway pressure.[9] This was primarily due to an increase in the ventilatory volume. The ventilatory efficiency remained disappointingly low.

The change of the volume of gas in the respiratory system per unit increase of the intratracheal pressure is a measure of the distensibility of the lungs and the restriction to expansion imposed by surrounding structures. This relationship of airway pressure to the volume of gas within the respiratory system is termed lung-thorax compliance,[10] a factor directly related to the total volume. In the determination of factors responsible for the inefficiency of ventilation during thoracic operations, the lung-thoracic compliance was studied. This paper presents a study of measurements of lung-thorax compliance made in anesthetized and unanesthetized patients with normal and diseased respiratory systems preceding, during, and following intrathoracic surgical operations.

METHODS AND SUBJECT MATERIAL

The methods used in this study have been described elsewhere in detail.[11] The method used to determine the lung-thorax compliance in the anesthetized patients was basically that described in 1946 by Rahn, Otis, Chadwick, and

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Fenn.[12] The unanesthetized patients were allowed to inhale, the airway was occluded and the airway pressure was measured with a pressure transducer (Statham P23A) during a state of voluntary complete relaxation. The airway occlusion was released and the volume of passively exhaled gas was measured through a pneumotachograph by the electronic integration of rate of gas flow against time. This was repeated 20 to 25 times and a volume/pressure curve was plotted as shown in Fig. 1. The average value was termed

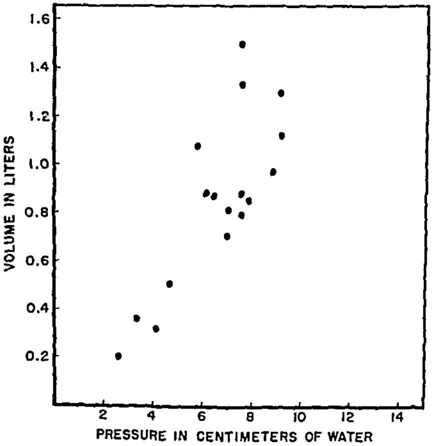

Fig. 1.—Lung-thorax compliance (anesthetized). (Reprinted through courtesy of A.M.A. Archives of Surgery)

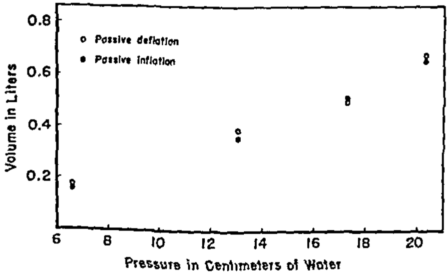

Fig 2.—Lung-thorax compliance (awake). (Reprinted through courtesy of A M A. Archives of Surgery.)

the lung-thorax compliance and was expressed as milliliters of gas per centimeter of H_2O pressure change. Multiple readings were required to obtain statistically significant results because of the scattering of the plotted points. "Training" of the patients was not used to increase the degree of relaxation nor were any "inaccurate" readings discarded once the study was st

This was to prevent bias which was found to occur readily in preliminary tests when "training" of the subjects or "selecting" of results was employed. A permanent photographic record was made of all measurements as they appeared on the oscilloscope.

During anesthesia, the airway pressure was measured as the lungs were inflated with oxygen during a period of apnea produced by hyperventilation or by neuromuscular blocking agents. The airway was occluded and the intratracheal pressure was measured. The airway occlusion was released and the amount of passive exhaled gas was measured. This was repeated 3 to 6 times in succession during which time all factors influencing lung-thorax compliance were kept constant. Immediately following this, the factor under investigation was changed and 3 to 6 more measurements were taken in succession. The volume/pressure values during inflation and deflation (6 to 12 readings) were averaged to give the mean lung-thorax compliance for each factor measured. The plotted points were virtually linear during anesthesia as shown in Fig. 2 and permitted valid comparison of relatively small changes in compliance with relatively few measurements.

RESULTS

1. *Lung-Thorax Compliance of Controls.*—The lung-thorax compliance of 9 normal, unanesthetized individuals was measured on 32 separate occasions. These individuals comprised the normal control group. All measurements were made in the supine position without sedation and before surgical operation. The results are shown in Table I. The average lung-thorax compliance was 240 ml./cm. H_2O.

2. *The Effect of Cardiac Disease and Pulmonary Disease on Lung-Thorax Compliance.*—The lung-thorax compliance was measured in a group of 9 un-

TABLE I. EFFECT OF CARDIAC DISEASE AND PULMONARY DISEASE ON LUNG-THORAX COMPLIANCE*

NORMAL CONTROLS		CARDIAC DISEASE			PULMONARY DISEASE		
CASE NUMBER	COMPLIANCE (ML./CM. H_2O)	CASE NUMBER	DISEASE	COMPLIANCE (ML./CM. H_2O)	CASE NUMBER	DISEASE	COMPLIANCE (ML./CM. H_2O)
N_1	350	C_1	Mitral stenosis	220	P_1	Bronchiectasis	80
N_2	400	C_2	Mitral stenosis	140	P_2	Bronchiectasis	290
N_3	130	C_3	Mitral stenosis	70	P_3	Bronchiectasis; empyema	210
N_4	150	C_4	Mitral stenosis	100	P_4	Lung carcinoma	130
N_5	260	C_5	Mitral stenosis	210	P_5	Lung carcinoma	90
N_6	170	C_6	Patent ductus arteriosus	80	P_6	Lung carcinoma	110
N_7	210	C_7	Patent ductus arteriosus	220	P_7	Metastases to lung	240
N_8	310	C_8	Cor pulmonale; emphysema	90	P_8	Emphysema; cor pulmonale	90
N_9	170	C_9	Cor pulmonale; emphysema	60	P_9	Emphysema; cor pulmonale	60
		C_{10}	Pulmonic stenosis	170			
		C_{11}	Pulmonic stenosis	120			
9 Cases	Average 240	11 Cases		Average 130	9 Cases		Average 140

*Unanesthetized.

anesthetized patients with pulmonary disease. All measurements were made in the supine position without sedation and before surgical operation. The results are also shown in Table I. The average lung-thorax compliance was 130 ml./cm. H_2O in the group with cardiac disease and 140 ml./cm. H_2O in the group with pulmonary disease. When the "t" test was employed, the difference in compliance between the normal control group and the cardiac disease group was found to be statistically significant at the one per cent level. The difference between the normal control group and the pulmonary disease group was significant between the one per cent and 5 per cent level. No significant difference in compliance existed between the patients with cardiac disease or pulmonary disease.

3. *Lung-Thorax Compliance in Unanesthetized Patients Before and After Intrathoracic Surgery.*—A group of 13 patients undergoing intrathoracic surgery was studied to determine if a change in lung-thorax compliance occurred during the operation and early postoperative period. The lung-thorax compliance was measured in the unanesthetized state in the supine position without sedation on the day preceding the operation. The lung-thorax compliance was measured in a similar manner on the fifth postoperative day or as soon thereafter as possible. The results are shown in Table II. There was a decrease in lung-thorax compliance from an average of 170 ml./cm. H_2O preoperatively to an average of 110 ml./cm. H_2O postoperatively. This difference was found to be statistically significant between the one per cent and 5 per cent level when the "t" test was employed.

TABLE II. LUNG-THORAX COMPLIANCE IN UNANESTHETIZED PATIENTS BEFORE AND AFTER INTRATHORACIC SURGERY

CASE NUMBER	OPERATION	PREOPERATIVE COMPLIANCE (ML./CM. H_2O)	POSTOPERATIVE COMPLIANCE (ML./CM. H_2O)
C_1	Mitral valvotomy	220	80
C_5	Mitral valvotomy	210	50
C_6	Division patent ductus	80	60
C_7	Division patent ductus	220	180
C_{10}	Pulmonic valvotomy	170	200
C_{11}	Pulmonic valvotomy	120	120
P_1	Lobectomy	80	70
P_2	Lobectomy	290	130
P_3	Lobectomy	210	120
P_4	Pneumonectomy	130	50
P_6	Pneumonectomy	110	100
P_7	Thoracotomy	240	200
P_8	Excision of bullae	90	90
13 Cases		Averages 170	110

4. *The Effect of General Anesthesia on Lung-Thorax Compliance.*—A group of 11 patients undergoing intrathoracic surgery was studied to determine if any change occurs during general anesthesia. The lung-thorax compliance was measured in the unanesthetized, unsedated, supine patient on the day preceding surgery. The compliance was measured again in the anesthetized, supine patient preceding the initiation of the operation. Several different types of general anesthetic agents were used. Apnea was obtained either by hyperventilation or by a combination of hyperventilation and neuromuscu

blocking agents. The compliance appeared to be independent of the method of producing apnea. The results are shown in Table III. There was a large, consistent decrease in the lung-thorax compliance from an average of 170 ml./cm. H_2O in the unanesthetized state to an average of 47 ml./cm. H_2O in the anesthetized state. The average decrease was 67 per cent.

TABLE III. EFFECT OF GENERAL ANESTHESIA ON LUNG-THORAX COMPLIANCE

CASE NUMBER	ANESTHETIC AGENT (1)*	APNEA INDUCED (2)*	UNANESTHETIZED COMPLIANCE (ML./CM. H_2O) (3)*	ANESTHETIZED COMPLIANCE (ML./CM. H_2O) (4)*	COMPLIANCE CHANGE (PER CENT)
C_2	T., E.	H., S.	140	42	-70
C_4	C.	H.	100	29	-71
C_5	C.	H.	210	49	-77
C_7	C.	H., S.	220	29	-87
C_{10}	T., C., E.	H., Sy.	170	47	-72
C_{11}	T., E.	H., Sy.	120	49	-59
P_2	C.	H.	290	46	-84
P_3	T., E.	H., S.	210	62	-71
P_5	T.	H., S.	90	50	-44
P_7	C.	H.	240	57	-76
P_8	C., E.	H.	90	61	-32
11 Cases		Averages	170	47	-68

*(1) E. = Ether; T. = Thiopentothal; C. = Cyclopropane.
(2) H. = Hyperventilation; S. = Succinylcholine; Sy. = Syncurine.
(3) All measurements taken in supine position the day preceding operation.
(4) All measurements taken in supine position before start of operation.

5. *The Effect of the Lateral Position on Lung-Thorax Compliance.*—A group of 7 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs with a shift from the supine position to the lateral position. The lung-thorax compliance was measured in the anesthetized state prior to the onset of surgery. The measurements were made just before and just after the position was changed in order to keep all other factors influencing lung-thorax compliance as constant as possible. The results are shown in Table IV. The changes in lung-thorax compliance that occurred were quite variable, ranging from a decrease of 47 per cent to an increase of 14 per cent with an average decrease of 10 per cent. In a separate series of patients undergoing miscellaneous types of surgery, obesity was found to be an important factor influencing lung-thorax compliance.

TABLE IV. EFFECT OF LATERAL POSITION ON LUNG-THORAX COMPLIANCE

CASE NUMBER	DISEASE	COMPLIANCE IN SUPINE POSITION (ML./CM. H_2O)	COMPLIANCE IN LATERAL POSITION (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_2	Mitral stenosis	42	48	+14
C_5	Mitral stenosis	49	41	-16
C_7	Patent ductus arteriosus	29	33	+14
P_2	Bronchiectasis	46	47	+2
P_3	Bronchiectasis; empyema	62	33	-47
P_5	Lung carcinoma	50	33	-34
P_8	Emphysema; cor pulmonale	61	59	-3
7 Cases				Average -10

There was an average increase in the lung-thorax of 136 per cent in one very obese patient with the shift from the supine to the lateral position. Her ventilatory effort dramatically improved as the heavy pendulous breasts and the anterior abdominal wall fell away from the thorax and abdomen. Repeated measurements confirmed this striking change.

6. *The Effect of the Open Chest on Lung-Thorax Compliance.*—A group of 5 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs when the chest is opened. The lung-thorax compliance was measured in the anesthetized state prior to opening the chest and was measured again after the Finochietto rib spreader was in place but before the lung was packed or retracted to gain exposure. Other factors influencing compliance, such as position of the patient and depth of anesthesia, were kept as constant as possible The results are shown in Table V. The change in lung-thorax compliance ranged from –19 per cent to +95 per cent, a rather wide range. There was an increase in compliance in 4 of the 5 cases with an average increase of 45 per cent for the entire group.

TABLE V. EFFECT OF OPEN CHEST ON LUNG THORAX COMPLIANCE

CASE NUMBER	COMPLIANCE OF CONTROL ($ML./CM.\ H_2O$)	COMPLIANCE WITH CHEST OPEN ($ML./CM.\ H_2O$)	COMPLIANCE CHANGE (PER CENT)
C_4	31	25	–19
C_5	41	80	+95
C_{10}	47	59	+26
C_{11}	49	52	+6
P_2	47	74	+58
5 Cases			Average +45

7. *The Effect of the Open Chest and Retraction of the Lung on Lung-Thorax Compliance.*—A group of 7 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs with retraction against the lung. The lung-thorax compliance was measured in the anesthetized state prior to opening the chest and was measured again after the Finochietto rib spreader was in place and the lung had been packed and retracted to gain exposure. Other factors influencing compliance, such as position of the patient and depth of anesthesia. were kept as constant as possible. The results are shown in Table VI. The change in lung-thorax

TABLE VI. EFFECT OF OPEN CHEST AND RETRACTOR ON LUNG THORAX COMPLIANCE

CASE NUMBER	COMPLIANCE OF CONTROL ($ML./CM.\ H_2O$)	COMPLIANCE WITH RETRACTOR ($ML./CM.\ H_2O$)	COMPLIANCE CHANGE (PER CENT)
C_2	48	38	–21
C_7	33	28	–15
C_{12}	30	12	–60
P_2	47	49	+4
P_3	33	29	–12
P_6	31	31	0
P_8	59	51	–14
7 Cases			Average –17

compliance ranged from –60 per cent to +4 per cent. There was a decrease in compliance in 5 of the 7 cases with an average decrease of 17 per cent for the entire group.

8. *Lung-Thorax Compliance at the Beginning and End of Intrathoracic Operations.*—A group of 5 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs during the operation. The lung-thorax compliance was measured in the anesthetized patient before the operation was started and again at the completion of the operation. The position of the patient and the depth of anesthesia were kept as nearly the same as possible for the two measurements. The measurement at the end of the operation was made with the thoracic incision closed, the lung expanded, and the drainage tube connected to an underwater seal. The results are shown in Table VII. The change in lung-thorax compliance ranged from –44 per cent to +3 per cent. A decrease in compliance occurred during the operation in 4 of the 5 cases with an average decrease of 16 per cent for the entire group at the end of the operation.

TABLE VII. LUNG-THORAX COMPLIANCE AT THE BEGINNING AND END OF INTRATHORACIC SURGERY

CASE NUMBER	COMPLIANCE AT BEGINNING (ML./CM. H_2O)	COMPLIANCE AT END (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_4	31	27	-13
C_{12}	30	31	+3
P_2	47	38	-19
P_3	62	57	-8
P_8	59	33	-44
5 Cases			Average -16

9. *The Range in Lung-Thorax Compliance Occurring During Intrathoracic perations.*—A group of 13 patients undergoing intrathoracic surgery was udied to determine the range of variation in the lung-thorax compliance ccurring during intrathoracic surgery. All of the measurements were made uring general anesthesia and under widely varying circumstances. A total f 59 measurements were taken on the 13 patients. The lowest measurement as compared to the highest in each patient and the difference was expressed

TABLE VIII. RANGE IN LUNG-THORAX COMPLIANCE IN INTRATHORACIC OPERATIONS

CASE NUMBER	HIGHEST COMPLIANCE (ML./CM. H_2O)	LOWEST COMPLIANCE (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_2	48	38	-21
C_4	31	25	-19
C_5	80	41	-49
C_7	43	25	-42
C_{10}	78	47	-40
C_{11}	52	39	-25
C_{12}	31	12	-61
P_2	74	38	-49
P_3	62	21	-66
P_5	50	33	-34
P_6	31	20	-35
P_7	57	24	-58
P_8	120	33	-72
13 Cases			Average -44

as the percentage decrease The results are shown in Table VIII. The percentage decrease ranged from −19 per cent to −72 per cent with an average decrease of 44 per cent

COMMENTS

Measurement of lung-thorax compliance in the unanesthetized patient presents the problem of obtaining a truly relaxed state. This makes demonstration of significant differences in lung-thorax compliance in unanesthetized patients relatively difficult as was mentioned earlier in the description of the method of measuring compliance Despite this difficulty, a significant difference was found to occur in this study when patients with pulmonary disease or cardiac disease were compared with normal controls Factors that would tend to produce decreased lung-thorax compliance in patients with pulmonary disease or cardiac disease are pulmonary fibrosis, the edema and induration of acute inflammation, pulmonary edema of cardiac failure, pulmonary hypertension, pleural effusion, pleural fibrosis, thoracic wall rigidity, and increased intra abdominal pressure Ferris, Mead, Whittenberger, and Saxton[10] reported finding a decrease in lung-thorax compliance in patients convalescing from anterior poliomyelitis Mead, Frank, Lindgren, Gaensler, and Whittenberger[13] studied the compliance of the lungs in a group of patients with rheumatic heart disease in which mitral stenosis was the predominant lesion and found a decrease in lung compliance when compared to a group of normal subjects Brown, Fry, and Ebert[14] also studied lung compliance in a group of patients with cardiac disease and found a decrease in compliance

A significant decrease in lung thorax compliance was found to occur in the interval from the day preceding the intrathoracic operation to the fifth postoperative day Among the factors, which are probably active in producing this change, are increased edema of the lungs, partial atelectasis due to accumulation of tracheobronchial secretions, irritative effects of gases or anesthetic agents, and involuntary splinting of the thorax due to a painful incision The lung-thorax compliance was previously measured in a similar manner in a group of patients undergoing operations other than thoracotomy No significant difference between the preoperative and postoperative compliance was found [11]

The large decrease in lung-thorax compliance which occurred with the patient under general anesthesia confirms previously reported studies [11, 15, 16] Nims, Conner, and Comroe[16] have discussed in detail the theoretical considera tion involved in this change They believed the values in the anesthetized state were more likely to be the true values because of the inability of man in the conscious state to completely suppress the tone of the respiratory muscles.

The more nearly linear relationship between pressure and volume in the anesthetized patient permitted the study of relatively small differences in lung-thorax compliance in relatively small groups of patients The changes in lung-thorax compliance that occurred in the shift from the supine to the lateral position illustrate the importance of two factors in this shift to the lateral position One factor is the extent of the diseas [illegible] most lung when the patient is in the lateral position and is illustrated in Table IV by Patient P_3 who had a chronic empyema and a markedly thickened pleura which incarcerated bronchiectatic middle and lower lobes and by Patient P_5 who had extensive disease due to bronchogenic carcinoma. In each case, a pronounced decrease in compliance occurred when the shift from the supine to the lateral position was made. A second factor influencing lung-thorax compliance in the shift from supine to lateral position is obesity of the patient, as was previously mentioned.

There was usually an increase in lung-thorax compliance when the chest was opened because of the effect of the increased compliance of the unrestricted lung. When the lung was packed away or retracted, however, a decrease in lung-thorax compliance occurred which usually resulted in a net decrease in compliance when compared to the control measurement. A rather surprisingly slight decrease in compliance occurred during the course of the intrathoracic surgery. A similar decrease was found to occur during operations other than thoracotomy in a group of patients previously studied.[11]

This study indicated that lung-thorax compliance in patients undergoing intrathoracic surgery is influenced by several factors. A rather wide range in compliance can be expected during the course of an operation, and there is variation in compliance between individuals. The effect changes in compliance would have on total volume of pulmonary ventilation during intrathoracic surgery becomes quite apparent. Were fixed inflation pressure used, the elevation of airway pressure necessary to provide an adequate tidal volume might at times be excessive if inflation alone were used to obtain adequate ventilation. Lung-thorax compliance is a factor that merits consideration in providing adequate pulmonary ventilation during general anesthesia for intrathoracic surgery.

SUMMARY

1. A study has been made of lung-thorax compliance in unanesthetized and anesthetized patients with normal and diseased respiratory systems preceding, during, and following intrathoracic surgery. The relation of compliance to adequate pulmonary ventilation is discussed.

2. There was a significant decrease in lung-thorax compliance in 11 unanesthetized patients with cardiac disease and 9 patients with pulmonary disease when compared to 9 normal controls.

3. A significant decrease in lung-thorax compliance occurred in 13 unanesthetized patients between the day preceding intrathoracic surgery and the fifth postoperative day.

4. General anesthesia in 11 patients produced an average decrease of 67 per cent in lung-thorax compliance when compared to the lung-thorax compliance in the unanesthetized state.

5. A variable change in lung-thorax compliance occurred when 10 anesthetized patients were shifted from the supine to the lateral position. A large decrease in compliance occurred in the lateral position in 2 patients with extensive disease in the uppermost lung. A large increase in compliance occurred in an extremely obese patient in the lateral position.

6 An average increase in lung thorax compliance of 45 per cent occurred in 5 patients when the chest was opened during intrathoracic surgery

7 An average decrease in lung thorax compliance of 17 per cent occurred in 7 patients when the lung was packed away or retracted to gain exposure when compared to the control measurement taken before the chest was opened

8 An average decrease in lung thorax compliance of 16 per cent occurred during intrathoracic surgery in 5 anesthetized patients when the immediate postoperative measurement was compared to the immediate preoperative measurement

9 A variation in the individual tested occurred in the lung thorax compliance of 13 patients during intrathoracic surgery There was an average decrease of 44 per cent when the minimum and maximum compliance were compared

10 These findings and their significance are discussed

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(For Discussion see page 474)

INEFFICIENT CARBON DIOXIDE ABSORPTION REQUIRING INCREASED PULMONARY VENTILATION DURING OPERATIONS

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THE occurrence of respiratory acidosis during surgical operations is due to inadequate removal of carbon dioxide from the body.[8] This should not occur if a sufficient volume of ventilation is supplied to remove carbon dioxide as rapidly as it is produced. The absence of pronounced clinical signs complicates the recognition of acidosis. Cyanosis may not occur because the oxygen available in anesthetic mixtures, being several times that of the atmosphere, facilitates adequate oxygenation even in the face of lower ventilatory volumes. Carbon dioxide removal does not enjoy this same advantage. The anesthetic mixture cannot be altered to enhance the removal of carbon dioxide. A normal tension of carbon dioxide (pCO_2) in the arterial blood indicates that the pulmonary ventilation is adequate.

The possibility that a defect in the CO_2 absorption mechanism might be responsible for some of the increase in required ventilation has been suggested previously.[7] Studies in our laboratory revealed incomplete carbon dioxide absorption in the anesthetic circuits in routine use in our hospital.[9] We are reporting here measurements of the effect of this incomplete CO_2 absorption on the ventilatory requirements.

METHODS

Preoperative sedation consisted of barbiturates followed by atropine and morphine or Demerol. Anesthesia was induced with intravenous thiopental sodium, oxygen, and succinylcholine. After the introduction of the endotracheal tube, anesthesia was continued with oxygen and ether. As soon as the tube was in place the gas sampling apparatus was attached to the endotracheal tube (Fig. 1). A closed circle type anesthetic apparatus was used. Ventilation was measured on the expiratory line by a dry test volume displacement gas flow meter. This meter has a flow rate capacity of 2.4 to 70 L. per minute with a resistance of less than 0.5 cm. of water at the higher flow rates. Expired gas was sampled in a chamber containing a spring driven fan (gas mixing chamber, Fig. 1). Pressures within the circuit were read from an aneroid type pressure

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gauge An oversized (Fig 2) 3,300 ml canister was inserted in the inspiratory line to ensure complete removal of carbon dioxide Concentrations of carbon dioxide in the gases were measured by a Liston Becker infrared absorption carbon dioxide analyzer

Prior to the start of the operation, a full calibration curve was established using known samples of carbon dioxide in oxygen available in a bank of gas cylinders The concentrations of carbon dioxide in the cylinders were determined by a micro Scholander technique[1,2] Periodic checks of the gas cylinders by this technique revealed a constant concentration of CO_2 until the cylinders were empty The concentrations ranged from 1 per cent to 11 per cent Immediately prior to taking a pertinent reading the machine was recalibrated at the operating table

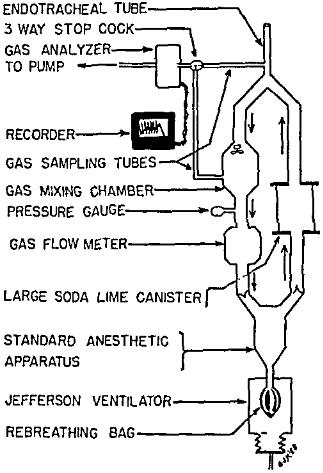

Fig 1 —Diagram of anesthetic circuit with sampling and measuring devices

A continuous partial sampling technique with a microcatheter cell was used as described by Collier[3] The sampling was at a constant rate which was generally 500 ml per minute Drift in calibration was avoided by allowing the analyzer to warm up overnight The analyzer cell was at the head of the patient A three way stopcock at the proximal end of the analyzer made it possible to selectively sample from either the end of the endotracheal tube or the mixing chamber One could thus read the concentration of CO_2 in the inspired air and end expired air, or the mixed expired air (*A*, *B*, and *a* in Fig 3) A continuous record was made on an Esterline Angus recorder Visual checks and occasional photographs were made of an expanded tracing on a simultaneously recording oscilloscope

The patient's lungs were ventilated by a positive negative pressure apparatus (Jefferson Ventilator) This made it possible to maintain volume or rate. A Cournand arterial needle was placed in a brachial artery. Observation of the end expiratory reading on the carbon dioxide analyzer was used as an indication of the pCO_2 of the alveolar air. When a steady state existed, with neither CO_2 accumulation nor excessive removal, the end expiratory reading remained constant. The patient was rendered apneic by hyperventilation. If succinylcholine had been used it was discontinued at this point. Pulmonary ventilation was then gradually decreased. The first evidence of voluntary breathing could be readily detected by a change in the oscilloscopic pattern. The concentration of CO_2 in the end expiratory gas at this point was noted. Ventilation was then increased slightly to render the patient apneic, lowering the end expiratory reading slightly. The end expiratory CO_2 concentration was then maintained constantly at this level by adjustment of the volume of ventilation. If desired by the anesthetist, succinylcholine was used after this point. A steady state was considered to be present if the end expiratory reading remained unchanged for ten minutes. This requirement was always met before pertinent measurements were made. The technique then consisted (Fig. 3) of measuring the ventilation while the carbon dioxide concentration of mixed expired gas was determined (*a*); recalibration (*b*); again measuring the ventilation and carbon dioxide concentration of the mixed

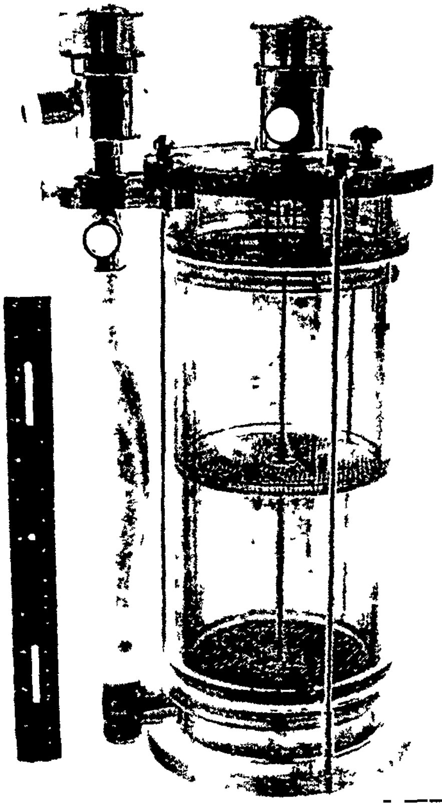

Fig. 2.—Photograph of large, 3,300 ml. canister used to ensure complete removal of carbon dioxide from the gases in the anesthetic circuit. (Designed by Drs. James O. Elam and Elwyn Brown.)

expired air. Coincident with the second measurement, the arterial blood sample was drawn. Samples were drawn in oiled syringes containing a small amount of heparin and a drop of mercury to facilitate mixing. Determination of pH and CO_2 content and calculation of arterial pCO_2 were carried out according to methods described previously.[10]

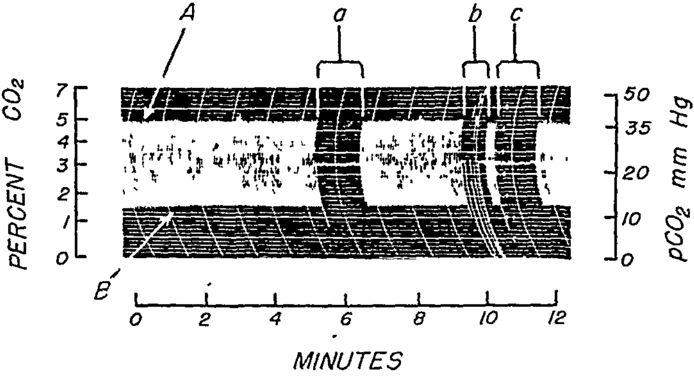

Fig 3 —Photograph of tracing of [illegible] bon dioxide in the respired gases A indicates the concentration o[illegible] end expired gas, and B the concentration of carbon dioxide in the [illegible] the concentration of carbon dioxide in the mixed expired gas was [illegible] was recalibrated during b, after ten minutes of a steady state. The measurement of a was repeated during c, the ventilation was measured, and an arterial blood sample drawn

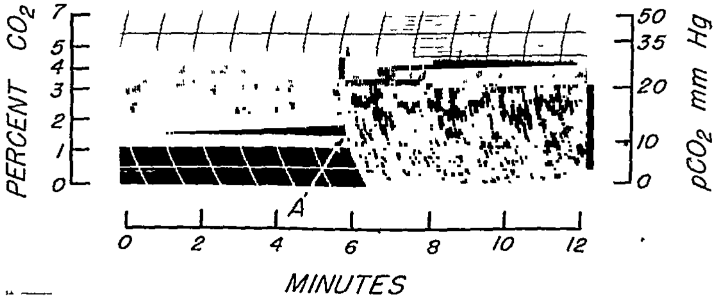

Fig 4 —Elimination of CO_2 from inspired gas by changing canister. Photograph of tracing of carbon dioxide concentration as in Fig 3 The large canister (Fig 2) was placed in the circuit at point A

Following the completion of these preliminary studies the oversized canister was removed from the inspiratory line. The conventional absorption canister in the anesthetic apparatus was then allowed to function. In all instances, the canisters were filled with fresh absorbent. As the carbon dioxide absorption became incomplete it could be noted on the tracing taken from the end of the endotracheal tube. The tracing no longer returned to zero during inspiration indicating the presence of carbon dioxide in the inspired air (*A* in Fig. 4). If no changes were made in the ventilation there was a gradual increase in the concentration of carbon dioxide in the end expired gas. In order to maintain the concentration of CO_2 in the end expired air at the previously determined point it was necessary to increase the ventilation. The increase in ventilation was accomplished by increasing the tidal volume (by widening the pressure differential). The duration of inspiration was equal to the duration of expiration. The ventilation and the mixed expired CO_2 concentration were measured periodically. Arterial blood samples were also drawn periodically when the patient was in a steady state.

The minute ventilation, the rate, the concentration of CO_2 in the inspired air, the end expired air and the mixed expired air were measured. From these measurements the alveolar pCO_2 and CO_2 output were calculated.

The alveolar ventilation may be defined as that volume of the total ventilation in which the pCO_2 of the inspired gas equilibrates with the pCO_2 of the arterial blood.

Alveolar ventilation ($\dot{V}_A$) was calculated by the formula:

$$\dot{V}_A = \frac{\dot{V}_{CO_2}}{F_{A_{CO_2}}} \tag{1}$$

where:

$\dot{V}_A$ = alveolar ventilation.

$\dot{V}_{CO_2}$ = the CO_2 output.

$F_{A_{CO_2}}$ = the concentration of CO_2 in the alveolar air.

Carbon dioxide output ($\dot{V}_{CO_2}$) was calculated as follows:

$$\dot{V}_{CO_2} = (\dot{V})\ (F_{E_{CO_2}}) \tag{2}$$

where:

$\dot{V}$ = minute ventilation.

$F_{E_{CO_2}}$ = concentration of CO_2 in mixed expired air.

Since the p_{CO_2} of arterial blood is accepted as the more representative value equation (1) becomes:

$$\dot{V}_A = \frac{\dot{V}_{CO_2}}{\dfrac{Pa_{CO_2}}{P_B\ -47}} \tag{3}$$

where:

Pa_{CO_2} = the tension of CO_2 in arterial blood.

P_B = prevailing barometric pressure.

47 = correction for water vapor pressure.

This formula would be correct in calculating the alveolar ventilation in patients breathing CO_2 free air but the presence of carbon dioxide in inspired air limits the amount of carbon dioxide which can be removed by a given volume of gas. This must be corrected in the formula as follows:

$$\dot{V}_A = \frac{\dot{V}\ (F_{E_{CO_2}} - F_{I_{CO_2}})}{\dfrac{Pa_{CO_2}}{P_B\ -47} - F_{I_{CO_2}}} \tag{4}$$

where:

$F_{I_{CO_2}}$ = the concentration of CO_2 in the inspired air.

The pCO_2 of alveolar air ($P_{A_{CO_2}}$) was calculated as follows:

(5) $PA_{CO_2} = (FA_{CO_2})\ (P_B\text{-}47)$
Where FA_{CO} = the concentration of CO in alveolar air and is considered equal to the concentration of carbon dioxide in the end expired air.

RESULTS

Observations as described above were made during thirteen operations on 12 patients. Every observation during these operations is recorded in Table I, provided that a steady state (constancy of end expired CO_2) had existed for ten minutes and that the tension of carbon dioxide in the arterial blood did not vary more than 4 mm. Hg between observations. The one exception is Case 1 where the lungs were congested in a patient with mitral stenosis and in whom, despite a total ventilation of 23.4 L., it was impossible to prevent a rise in carbon dioxide tension of 8 mm. Hg when rebreathing approximately one per cent carbon dioxide. In Cases 1 and 2, the thorax was open. In the subsequent cases, the observations were made on patients with a closed thorax because it was found easier to achieve a steady state when there was no possibility of variable compression of the lung. The pressures used during inspiration and expiration are listed in Column 3. In only one instance (Case 10) was it necessary to appreciably increase the rate in order to increase the ventilation.

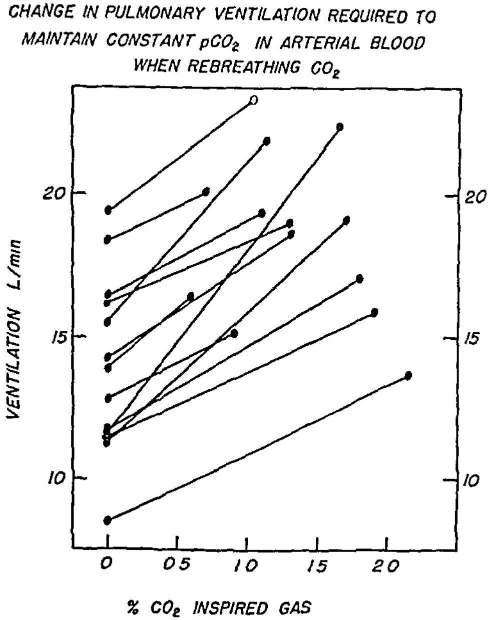

Fig. 5.—In one instance (open circle) it was not possible to compensate for 1.08 per cent carbon dioxide in the inspired gas with a ventilation of 23.4 L. per minute.

taken from the end of the endotracheal tube. The tracing no longer returned to zero during inspiration indicating the presence of carbon dioxide in the inspired air (*A* in Fig. 4). If no changes were made in the ventilation there was a gradual increase in the concentration of carbon dioxide in the end expired gas. In order to maintain the concentration of CO_2 in the end expired air at the previously determined point it was necessary to increase the ventilation. The increase in ventilation was accomplished by increasing the tidal volume (by widening the pressure differential). The duration of inspiration was equal to the duration of expiration. The ventilation and the mixed expired CO_2 concentration were measured periodically. Arterial blood samples were also drawn periodically when the patient was in a steady state.

The minute ventilation, the rate, the concentration of CO_2 in the inspired air, the end expired air and the mixed expired air were measured. From these measurements the alveolar pCO_2 and CO_2 output were calculated.

The alveolar ventilation may be defined as that volume of the total ventilation in which the pCO_2 of the inspired gas equilibrates with the pCO_2 of the arterial blood.

Alveolar ventilation ($\dot{V}_A$) was calculated by the formula:

$$(1) \qquad \dot{V}_A = \frac{\dot{V}_{CO_2}}{F_{A_{CO_2}}}$$

where:

$\dot{V}_A$ = alveolar ventilation.
$\dot{V}_{CO_2}$ = the CO_2 output.
$F_{A_{CO_2}}$ = the concentration of CO_2 in the alveolar air.

Carbon dioxide output ($\dot{V}_{CO_2}$) was calculated as follows:

$$(2) \qquad \dot{V}_{CO_2} = (\dot{V})\ (F_{E_{CO_2}})$$

where:

$\dot{V}$ = minute ventilation.
$F_{E_{CO_2}}$ = concentration of CO_2 in mixed expired air.

Since the pco_2 of arterial blood is accepted as the more representative value equation (1) becomes:

$$(3) \qquad \dot{V}_A = \frac{\dot{V}_{CO_2}}{\dfrac{Pa_{CO_2}}{P_B\ -47}}$$

where:

Pa_{CO_2} = the tension of CO_2 in arterial blood.
P_B = prevailing barometric pressure.
47 = correction for water vapor pressure.

This formula would be correct in calculating the alveolar ventilation in patients breathing CO_2 free air but the presence of carbon dioxide in inspired air limits the amount of carbon dioxide which can be removed by a given volume of gas. This must be corrected in the formula as follows:

$$(4) \qquad \dot{V}_A = \frac{\dot{V}\ (F_{E_{CO_2}} - F_{I_{CO_2}})}{\dfrac{Pa_{CO_2}}{P_B\ -47} - F_{I_{CO_2}}}$$

where:

$F_{I_{CO_2}}$ = the concentration of CO_2 in the inspired air.

The pCO_2 of alveolar air ($P_{A_{CO_2}}$) was calculated as follows:

(5) $P_{A_{CO}} = (F_{A_{CO_2}})\ (P_B\ 47)$

Where $F_{A_{CO}}$ = the concentration of CO in alveolar air and is considered equal to the concentration of carbon dioxide in the end expired air

RESULTS

Observations as described above were made during thirteen operations on 12 patients Every observation during these operations is recorded in Table I, provided that a steady state (constancy of end expired CO_2) had existed for ten minutes and that the tension of carbon dioxide in the arterial blood did not vary more than 4 mm Hg between observations The one exception is Case 1 where the lungs were congested in a patient with mitral stenosis and in whom despite a total ventilation of 23 4 L, it was impossible to prevent a rise in carbon dioxide tension of 8 mm Hg when rebreathing approximately one per cent carbon dioxide In Cases 1 and 2, the thorax was open In the subsequent cases, the observations were made on patients with a closed thorax because it was found easier to achieve a steady state when there was no possibility of variable compression of the lung The pressures used during inspiration and expiration are listed in Column 3 In only one instance (Case 10) was it necessary to appreciably increase the rate in order to increase the ventilation

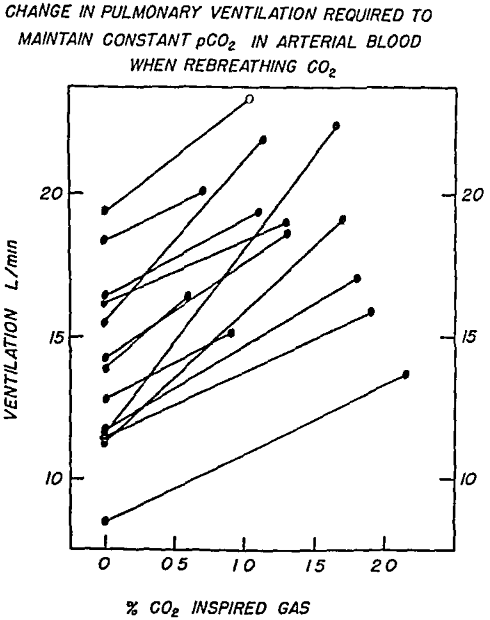

Fig 5—In one instance (open circle) it was not possible to compensate for 1 08 per cent carbon dioxide in the inspired gas with a ventilation of 23 4 L per minute

TABLE I

CASE NUMBER	OPERATION	PRESSURE CM.H_2O	RATE f	TOTAL VENTILATION		PER CENT CO_2 INSPIRED GAS	PER CENT CO_2 EXPIRED GAS	ALVEOLAR VENTILATION		pCO_2 ARTERIAL BLOOD MM. HG Pa_{CO_2}	pCO_2 END EXPIRED GAS MM. HG $P_{A_{CO_2}}$
				L./MIN. BTPS $\dot{V}$	L./M_2/MIN. BTPS $\dot{V}$			L./MIN. BTPS $\dot{V}_A$	L./M_2/MIN. BTPS $\dot{V}_A$		
1	Mitral valvotomy	+15- 6	18	19.4	11.7	0.00	1.15	4.2	2.5	38	25
		+16- 2	20	23.4	14.1	1.08	2.07	4.4	2.6	46	34
2	Repair of hiatal hernia	+12- 7	12	12.7	7.2	0.00	1.60	3.4	1.9	43	39
		+14- 5	12	15.3	8.7	0.90	2.30	4.7	2.7	39	30
3	Laparotomy	+10- 6	16	15.5	7.9	0.00	1.35	4.0	2.0	37	23
		+10- 6	15	16.8	8.5	0.60	2.00	4.9	2.5	38	28
		+15- 5	15	22.1	11.3	1.13	2.25	6.8	3.4	36	25
4	Abdominal aortic graft	+ 9- 8	18	16.5	9.8	0.00	1.13	2.7	1.6	48	32
		+11- 9	20	19.4	11.5	1.10	1.95	3.0	1.8	46	32
5	Cholecystectomy	+11-10	14	18.4	8.8	0.00	----	--	--	44	30
		+13- 6	13	20.1	9.6	0.70	1.60	3.2	1.5	45	26
6	Excision, rectum	+ 8- 8	16	13.5	8.6	0.00	1.95	5.2	3.3	36	33
		+14- 9	16	18.1	11.6	0.90	2.40	6.3	4.0	37	33
		+17- 9	16	19.0	12.2	1.33	2.76	6.9	4.4	38	34
7	Gastrectomy	+ 8- 5	14	14.2	6.8	0.00	2.05	5.3	2.6	39	34
		+10- 9	14	18.7	9.0	1.30	2.65	6.1	2.9	39	34
8	Thyroidectomy	+ 6- 5	16	11.7	7.4	0.00	2.18	5.5	3.5	34	34
		+ 9- 8	17	17.2	10.9	1.80	3.05	6.8	4.3	36	33
9a	Excision, tumor parotid	+10- 2	16	11.5	7.1	0.00	1.08	3.9	2.4	39	32
		+11- 5	16	15.9	9.8	1.90	3.10	5.7	3.5	38	31
9b	Scalenectomy	+ 8- 6	13	13.9	8.5	0.00	1.55	3.8	2.4	40	28
		+12- 6	13	18.0	11.1	0.60	1.75	4.7	2.9	36	28
10	Colectomy	+ 9- 5	14	11.6	6.7	0.00	1.65	4.6	2.6	30	26
		+10- 4	14	13.9	8.0	1.55	1.90	4.9	2.8	32	27
		+13- 6	20	22.4	12.9	1.65	2.70	9.8	5.6	29	25
11	Mastectomy	+ 7- 5	14	11.4	7.6	0.00	2.00	4.8	3.2	34	31
		+ 9- 8	15	19.2	13.1	1.70	2.65	6.4	4.4	33	31
12	Thyroidectomy	+ 6- 5	14	8.5	5.0	0.00	----	--	--	51	28
		+ 8- 5	14	12.3	7.1	0.80	----	--	--	52	27
		+ 8- 6	14	13.7	8.0	2.15	----	--	--	54	29

Total and alveolar ventilation are expressed in gas volumes at body temperature, prevailing barometric pressure, and saturated with water vapor. The ventilation figures have also been related to body surface area in order to permit comparison between patients The indicated concentration of carbon dioxide in the expired gas refers to the mixed expired gas and not to the concentration

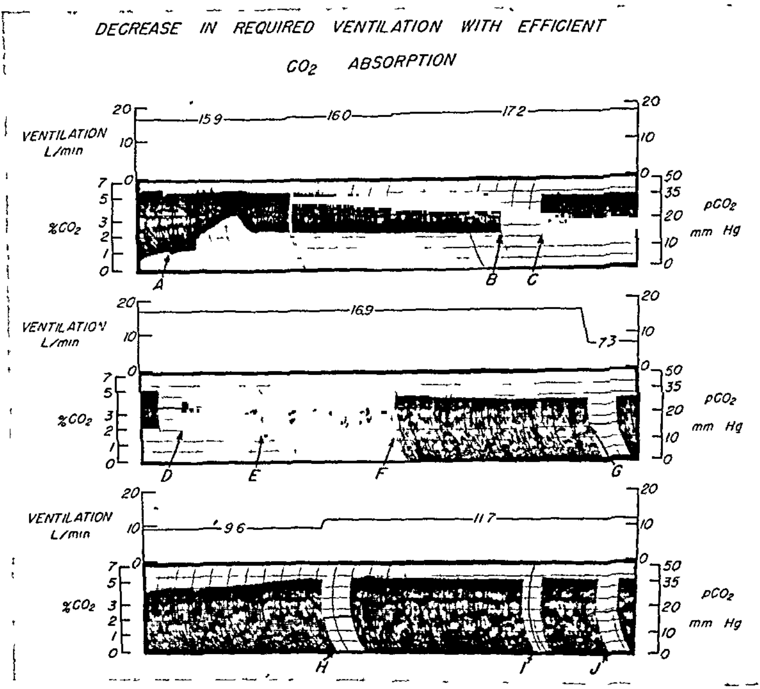

Fig 6 —Tracing of carbon d   graph of ventilation, during oper-
ation in Case 8 The concentratic   e inspired gas rose rapidly at A
The carbon dioxide in the mixed   from B to C. A second similar
measurement was completed at   ady state The ventilation was
measured at the same time and   calculated Carbon dioxide ab-
sorption was obviously incomplete   reathing gas containing approxi-
mately 2 per cent carbon dioxide   the anesthetic machine containing
"rested" absorbent was switched   effect. At F, the large canister
(Fig 2) was substituted for the c[illegible] in the anesthetic machine. This immediately resulted in complete absorption and no carbon dioxide in the inspired gas (bottom of tracing) and a reduction in the carbon dioxide of the end expired gas (top of tracing) until the ventilation was decreased at G The carbon dioxide in the end expired gas then rose until point H At I, the apparatus was recalibrated and at J the carbon dioxide in the mixed expired gas was determined after ten minutes of a steady state

at the end of expiration. This latter concentration is expressed in millimeters of mercury in the last column of the table. The observations made are listed in chronological order during each operation with the exceptions of Ca 11, and

TABLE I

CASE NUMBER	OPERATION	PRESSURE CM.H_2O	RATE f	TOTAL VENTILATION		PER CENT CO_2 INSPIRED GAS	PER CENT CO_2 EXPIRED GAS	ALVEOLAR VENTILATION		pCO_2 ARTERIAL BLOOD MM. HG Pa_{CO_2}	pCO_2 END EXPIRED GAS MM. HG PA_{CO_2}
				L./MIN. BTPS $\dot{V}$	L./M_2/MIN. BTPS $\dot{V}$			L./MIN. BTPS $\dot{V}_A$	L./M_2/MIN. BTPS $\dot{V}_A$		
1	Mitral valvotomy	+15- 6	18	19.4	11.7	0.00	1.15	4.2	2.5	38	25
		+16- 2	20	23.4	14.1	1.08	2.07	4.4	2.6	46	34
	of hiatal	+12- 7	12	12.7	7.2	0.00	1.60	3.4	1.9	43	39
		+14- 5	12	15.3	8.7	0.90	2.30	4.7	2.7	39	30
		+10- 6	16	15.5	7.9	0.00	1.35	4.0	2.0	37	23
		10- 6	15	16.8	8.5	0.60	2.00	4.9	2.5	38	28
		[illegible]	15	22.1	11.3	1.13	2.25	6.8	3.4	36	25
				16.5	9.8	0.00	1.13	2.7	1.6	48	32
				19.4	11.5	1.10	1.95	3.0	1.8	46	32
					8.8	0.00	----	--	--	44	30
					9.6	0.70	1.60	3.2	1.5	45	26
						0.00	1.95	5.2	3.3	36	33
						0.90	2.40	6.3	4.0	37	33
						[illegible]	2.76	6.9	4.4	38	34
							2.05	5.3	2.6	39	34
							2.65	6.1	2.9	39	34
								5.5	3.5	34	34
								6.8	4.3	36	33
									2.4	39	32
									3.5	38	31
										40	28
										36	28
										[illegible]	26
											27
											25

complete absorption of carbon dioxide was achieved by using the large canister, point *"F,"* the ventilation could be reduced from approximately 17 L. per minute to less than 12 L. per minute, maintaining the same tension of carbon dioxide in the arterial blood, for example, 35 mm. Hg.

The disparity between the tension of carbon dioxide in the expired gas at the end of expiration measured by the infrared analyzer and the tension of carbon dioxide in the arterial blood calculated from the carbon dioxide content and pH is apparent. These figures appear in the last two columns of Table I. Here again under the conditions of anesthesia with controlled mechanical ventilation, unequal distribution of the respired gases in the pulmonary alveoli may be largely responsible for the difference in these figures. In our own experience and in that of Collier and his associates[3] with conscious patients, this disparity practically disappears. As would be expected, the disparity increases with increase in the physiologic dead space as illustrated in Fig. 7. In this figure, the physiologic dead space is derived by subtracting the per cent of the total ventilation which is effective (alveolar ventilation) from 100 per cent. Under normal conditions in conscious individuals, the physiologic dead space amounts to approximately 30 per cent of the total ventilation.[4] In the observations reported here under anesthesia with controlled mechanical ventilation, the physiologic dead space varied between 55 and 90 per cent. At 55 per cent, the tension in the arterial blood equalled that in the end expired gas. Between 55 and 65 per cent, the difference amounted to less than 5 mm. Hg.

DISCUSSION

Previous publications from this laboratory and elsewhere have documented the frequency of the occurrence of respiratory acidosis during surgical operations.[2, 6, 7, 8, 13] A method of avoiding such acidosis by the use of a mechanical positive and negative ventilator has been described.[1, 10] The large increase in pulmonary ventilation required to avoid respiratory acidosis has not been adequately explained. A number of factors are undoubtedly contributory. We have found that one of these factors is incomplete absorption of carbon dioxide in two standard models of anesthetic machines in use in our hospital. The incomplete absorption was found to be due to (1) improper channelling of the gases through the anesthetic apparatus, and (2) the use of a widely advertised carbon dioxide absorbent which proved to be far less efficient than U.S.P. soda lime. These findings will be reported in detail elsewhere.[9]

We have reported here the increase in pulmonary ventilation required to prevent an increase in the pCO_2 of arterial blood when the patient rebreathes carbon dioxide in the concentrations produced by these inadequate anesthetic machines. The required increase in pulmonary ventilation under these circumstances is significant, varying between 9 and 93 per cent. It seems likely that our experience with the apparatus and material supplied by national concerns is probably being duplicated in many other hospitals. This assumption could be substantiated by appropriate studies.

comfortable. This conscious patient could adapt his alveolar ventilation to the inspired CO_2. Therefore, the end expiratory CO_2 remained at 6 per cent for 45 minutes. However, during this time alveolar ventilation increased from about 6 L. a minute to about 20 L. a minute while the inspired CO_2 increased from 0.3 per cent to 2.5 per cent. Finally, at the end of 105 minutes this man could no longer compensate for an inspired CO_2 concentration of 5.8 per cent by increase in ventilation and even this conscious subject began to show respiratory acidosis with an increase of end expiratory CO_2 to 7.8 per cent.

(Slide) Here are plotted the inspired CO_2 rising from 0.3 per cent up to 5.8 per cent at 105 minutes and the alveolar ventilation from 6 L. to 28 L. per minute. This situation would of course have been much worse in an anesthetized patient because he cannot increase the tidal volume as this individual did but must increase alveolar ventilation by the much less efficient means of increase in respiratory rate.

This one-pound canister is thus a compromise and the most important factor in this compromise is time. I think if the ordinary canister is changed faithfully every 15 minutes, then the problem is probably not too great. If the size of the canister and the type of the soda-lime are changed so as to absorb efficiently all CO_2 for long periods, then we would have to give some thought to the fact that respiratory resistance is increased, and we are then committed to some means of ventilating these patients artificially during anesthesia.

DR. HERBERT C. MAIER, New York, N. Y.—This has been a most valuable symposium and I would like to compliment those who presented papers. During the past year we have used a Jefferson ventilator with its positive and negative phase during anesthesia for lung surgery, and I would like to show you 2 illustrative cases in which we had previously hesitated to operate without the aid of positive-negative ventilation.

(Slide) In this patient on the left side there is a large empyema with pleural calcification, and on the right side a nonfunctioning lung with a fixed diaphragm. Obviously this patient's respiratory reserve was extremely low. The only portion of her chest that could move, in other words, the only portion of the bellows mechanism that was effective was the left diaphragm. The first time we took her to the operating room and employed ordinary ventilation with manual compression of the anesthesia bag, there was rapid deterioration of the circulation and we were unable to obtain any appreciable depth of anesthesia due to lack of adequate ventilation, and there was obvious congestion of the cervical veins. Later this patient was operated upon with the help of the Jefferson ventilator, which permitted adequate ventilation of the left lung and better motion of the diaphragm, without circulatory impairment.

(Slide) This is the postoperative film after decortication showing a very satisfactory re-expansion of the lung.

(Slide) This is a film of a patient with severe kyphoscoliosis who had collapse of the lung on one side due to progressive distention of pulmonary cysts, with only a little expanded lung tissue remaining in the hilar area. This patient was in obvious severe respiratory distress, but through an anterior thoracotomy approach, again with the aid of the Jefferson ventilator at the second attempt, we were able to remove the cysts successfully and get lung expansion.

In conclusion, I would like to emphasize that both these patients were able to return to work within two months following operation because the main hurdle was the proper management of their ventilation during an operation which was designed to improve their critically reduced pulmonary function.

DR. JEROME R. HEAD, Chicago, Ill.—The presentation of these interesting and excellent papers before this Association seems to me important and appropriate. However much the anesthesiologists have tried to argue us out of the contention, the responsibility for the anesthesia lies with the surgeon, and for the surgeon to pass it entirely to the anesthesiologist is against Hippocratic principles and against the principles of modern law. The findings presented in these papers also seem encouraging. It means that what we had almost come to accept as a fated and unavoidable accident is becoming an understandable phenomenon and a preventable phenomenon Among all primitive peoples, when anything is not understood and is potentially disastrous, it is attributed to evil spirits, and I would confess that my attitude toward cardiac arrest has been heretofore largely on that basis One of the evil spirits has been the anesthesiologist but, more specifically and less facetiously, for a long time I placed my faith in ether As a young man I went into the operating room and was given a can of ether and a mask and told to put people to sleep They all lived, which was very surprising to me, and I attributed it entirely to the fact that you could not kill people with ether But I found out, over a period of years, that I had had three cardiac arrests under pure ether anesthesia, all of them during induction I am sure now that this was because of inadequate relaxation and of multiple attempts to insert an intratracheal tube I was finally convinced that a long difficult induction with multiple attempts to insert a tube was bad I should have said also that one of my evil spirits was curare, I turned to Pentothal and nitrous oxide and to controlled respiration, and I put my faith in that, as one would put his faith in a god or a dance or whatever you have I got along very well with that until I realized that controlled respiration was of two kinds, either manual or mechanical Recently I had a case of cardiac arrest due, I feel sure, to the fact that the anesthesiologist became so interested in watching the resident put a catheter into a vein in the leg that he forgot to pump the bag That is a human error and, as a result of it, I have gone to mechanical respiration and to hyperventilation Hyperventilation may have certain drawbacks but they are much less than those of underventilation Therefore, at the present time, as soon as I make the incision I begin to say—'The blood is black, come on, get going, the blood is black ' I do that at intervals all through the operation and so far it has worked I have not had a cardiac arrest for a year

These papers are very interesting and very important but they do not show what happens during cardiac arrest I feel that every anesthetic agent at the present time should be considered experimental, that any anesthesiologist who is not checking himself and being checked by blood oxygen readings, by CO analyses, and by the running electrocardiogram, is not being a good anesthesiologist The only way in which we will learn exactly what happens, exactly what causes cardiac arrest, is to have such data on a group of patients who have suffered cardiac arrest

DR PAUL NEMIR, JR, Philadelphia Pa —I too wish to congratulate the authors of these excellent papers We have been interested in the problem of respiratory acidosis and I wish to comment briefly on some work being done in our department by Dr Hrant Stone and Dr David Seligson on the problem of carbon dioxide retention Evidence is available which indicates that other buffer systems exist in the body to absorb high concentrations of retained carbon dioxide These buffer systems are present in muscle masses and bone and are capable of absorbing many times the amount of carbon dioxide that is handled by the blood During surgical procedures, particularly thoracic surgical procedures, when carbon dioxide retention occurs and the arterial pCO rises, serious changes in other blood constituents usually will not occur unless the pCO_2 exceeds values of 90 to 100 However, if it increases above this level, the serum potassium rises In the presence of normal kidney function, potassium excretion maintains a normal blood level of this constituent However, during surgery many factors such as hypotension, dehydration, and shock depress renal function and thus cause a hyperkalemia In addition, many anesthetic agents and drugs used during anesthesia produce a decreased urine flow, due to stimulation of the antidiuretic hormone of the posterior pituitary The presence of pre existing renal disease may further prevent the kidneys from effectively eliminating potassium from the blood By controlled occlusion of the ureters it has been possible to detect these changes in the presence of acidosis of sufficient magnitude In terms of time, the changes in potassium level were significant in one and one half hours which is a short time in terms of the present duration of many surgical procedures It is conceivable that cardiac arrest which occurs following certain types of surgery without apparent cause, actually represents a hyperkalemic death secondary to severe respiratory acidosis and impaired renal funct

DR. GEORGE H. A. CLOWES, JR., Cleveland, Ohio.—This has been an interesting session. I agree with Dr. Head and Dr. Nemir that it is all very well to say that carbon dioxide rises or that respiratory exchange is inadequate. What we need to know is the effects of these occurrences upon the patient, and more particularly upon his heart, circulation, and nervous system.

In an attempt to understand more of the mechanisms entering into the production of circulatory failure during surgery we have been trying to sort out the effects of the various components which enter into cardiac arrest: hypercapnia, hypoxia, anesthetic agents, and hypotension. This has been approached both from hemodynamic and biochemical standpoints. In essence, pure carbon dioxide accumulation of the degree described today produces very little effect if other factors remain equal. It is only when the respiratory mixture contains more than 15 per cent CO_2 that we begin to see any changes of note. Mixtures containing more than 30 per cent are required to produce significant brain depression or shifts in serum potassium in man.

Hypoxia is a different matter. Little effect is produced on any of the systems except a discharge of the adreno-sympathetic mechanism until the arterial oxygen level falls below a "critical level" of approximately 4 volumes per cent. At this time events progress rapidly. Recent studies in our laboratory show that cardiac output falls while peripheral resistance and venous pressure rise. Thus, this represents a failure of the cardiac muscle and an inability to continue its normal pumping action.

There are shifts in serum electrolytes which accompany both hypoxia and hypercapnia. Those relating to potassium have been described by Seeley, ourselves, and others. The effects on calcium and magnesium are at times dramatic, yet we cannot understand them or classify them at present.

As for anesthetic agents and their effects on the homeostatic mechanisms I have been discussing, I have less firsthand knowledge.

I hoped that Dr. Beecher and some of the other gentlemen who spoke this afternoon would say a little bit more about these various things we are trying to prevent. At the present time, anesthesia remains an art regardless of the scientific information we may have concerning it. With the same amount of knowledge and equipment one man will be able to avoid too much anesthetic agent and maintain a good patient, whereas another man will not.

DR. N. K. JENSEN, Minneapolis, Minn.—As a thoracic surgeon interested in this problem for the last ten years I was delighted to hear this fine series of papers. I think we are all very much in the position of gradually emerging from the era, Dr. Head described so adequately, of mystery and magic. We have been flying by the seat of our pants, and we are gradually now gathering data on the atmosphere we operate in and are ready to start flying by instrumentation, which is very much safer. Dr. Stead and Dr. Martin and I have studied this problem for about ten years and we have discovered that if the recording equipment is turned away from the anesthesiologist he has no idea where he is. If it is where he can watch it he keeps things well in balance. If he knows the CO_2 content in the expired air and the oxygen saturation he keeps things in balance, but by guess he guesses very poorly.

This equipment is available and can be used. Good infrared CO_2 analyzers are available. Good oxygen content equipment is available, and it should be incorporated in the anesthesia apparatus today. I don't think any of us want to fly home from this meeting in the "Spirit of St. Louis," with a watch hanging for a gravity meter on the dashboard—you just cannot fly safely that way. I do not think you can give decent anesthesia with the equipment we have at the present time. I am sure the equipment can be made available, and I think we should encourage anesthesiologists and maufacturers to make it so.

One other point was well made by Dr. Papper; the hazard of the period of intubation. When the period of intubation starts, somebody should start holding his breath in that room, and if the patient is not intubated and being ventilated by the time the observer must breathe, intubation should be abandoned and the patient again well ventilated before a new effort is made The average individual, by measurement, the average healthy interne, can hold his breath for about one minute and in that time his arterial pH drops from 7 4 to 7 3, at 7 25 he is unconscious and the CO retained is a potent anesthetic agent Likewise, in the recovery period when the anesthesiologist says, "I don't know why this old fellow doesn't wake up, I only used 400 mg of Pentothal"—that man has been anesthetized probably for the last two hours on carbon dioxide and if you run a pH on him you will be amazed It will be about 7 1, he will die at about 6 9 You may have to take this patient back to a gas machine and ventilate him for awhile to eliminate enough CO_2 to bring the pH to physiologic levels before he will wake up The confusion that occurs between the anesthesiologist, carbon dioxide, and the anesthetic agent is one of the real problems in the postintratracheal phase Unless the carbon dioxide is eliminated sufficiently, spontaneous ventilation is not deep enough to clear the remainder from the blood Reintubation with further artificial ventilation is essential until the anesthetic effects of respiratory acidosis are eliminated *Without constant measurement of either CO content of alveolar air or* arterial pH it is impossible to determine if the continuing anesthesia is due to anesthetic agent or retained CO Proper diagnosis precedes proper treatment

DR RICHARD M PETERS, Chapel Hill, N C—In the discussion of the change in compliance in patients under anesthesia, I think it is important to point out that an increase in the concentration of CO in the alveoli causes bronchoconstriction which is real and can make a lung completely unable to deflate passively This is also true with hypoxia and it may well be that one of the things which changes the compliance in these animals is a loss of pulmonary volume due to increasing portions of the lung being shut off during periods of bronchoconstriction associated with anoxia or hypercapnia If compliance and airway resistance are measured simultaneously, there is a much greater rise in bronchial resistance with accumulated CO_2 or anoxia than there is a change in compliance If a patient becomes hypercapnic or anoxic, it will be much harder to achieve good ventilation because of the bronchoconstriction which occurs with these two phenomena Fortunately, this is a vagal reflex and can be reversed by atropine, and if a patient cannot be ventilated for these reasons, it may well be that the use of large doses of atropine will relieve the bronchospasm so that increased ventilation can be done feasibly to correct hypercapnia

DR FRANK F ALLBRITTEN, JR, Kansas City, Kan—Dr Peters mentioned the increased concentration of CO_2 affecting compliance The patients that were reported on were hyperventilated preceding the measurement of the compliance to the point of apnea I think the measurements given have no relationship to retained carbon dioxide

I would like again to stress that at the present time it seems the volume of ventilation is directly proportional to the effective ventilation, and if there is merit in a vacuum phase for deflation of the lung in ventilation, it probably is that of increasing the volume of ventilation within the pressure ranges compatible with the safety of the patient

The absorption of carbon dioxide discussed by Dr Nealon is an additional important factor The demonstration that ventilatory volume could be significantly decreased and still maintain an adequately effective ventilation explains, in part, the increased total volume of ventilation required by anesthetized patients We think that lung compliance also plays a part These are two factors, then, which may play a part in the increased volume of ventilation necessary to maintain adequate effective ventilation in anesthetized patients I suspect that other factors will soon be evident

DR JOHN H GIBBON, JR, Philadelphia, Pa—I too have found all these papers very interesting I should like to make just a couple of comments, one, with regard to the paper of Drs Gordon and Fyre concerning the use of the negative phase in the open chest Obviously in the vast majority of patients it is not necessary to use a negative phase in the open chest However, I would like to heartily endorse Dr Maier's remarks In several patients with marked emphysema we have had to discontinue open thoracic operations when positive pressure ventilation alone was used When a negative phase was added, these same patients were adequately ventilated and the open thoracic operations were successfully completed. Adding the negative phase eliminated the distended lung obscuring the operative field. Despite what Dr. Gaensler said about the theoretical aspects, practically it works; and there are cases in which you will occasionally need a negative phase with an open chest.

With regard to what Dr. Gaensler reported about a widely used carbon dioxide absorbent, this is what Dr. Nealon referred to. We found this absorbent rather worthless. U.S.P. soda-lime was infinitely better. We should have given credit, on the slide illustrating the large canister, to Dr. E. S. Brown who devised it. I might add that this canister, filled with ordinary U.S.P. soda-lime, has been used in prolonged operations three or four hours a day for as long as two weeks without changing the soda-lime and with efficient carbon dioxide, absorption.

Finally, I regard the timing as relatively unimportant. Whether you use an equal duration of inflation and deflation, or a deflation of twice the duration of inflation, or 30 per cent of the respiratory cycle for inflation and 70 per cent for deflation, we still believe that the more important factor is the mean pressure exerted during the respiratory cycle. Perhaps, as Gordon and Fyre believe, the timing is of some importance, but I do not think that you can arrive at that conclusion merely by determination of the blood pressure. We have tried in normal healthy young people with an intact thorax, to reduce the blood pressure by employing a high positive pressure during inflation, omitting the negative pressure during deflation, and have been unable to affect the blood pressure at all. Whereas, in elderly weak patients with hypovolemia the blood pressure will drop to shock levels under these circumstances.

AORTIC VALVULOTOMY UNDER DIRECT VISION DURING HYPOTHERMIA

F JOHN LEWIS, M D ,* NORMAN E SHUMWAY, M D (BY INVITATION), SUAD A NIAZI, M D (BY INVITATION), AND ROBERT B BENJAMIN, M D (BY INVITATION)
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INTRODUCTION

EVEN optimistic surgeons cannot hide a certain disappointment with current operations for aortic stenosis Many less enthusiastic and perhaps less voluble practitioners have never tried these operations, or because of failures, abandoned them There are at least two important reasons why surgery for aortic stenosis is unsatisfactory First, and doubtless more important, the aortic valve cusps are usually severely damaged—not just adherent to one another—by the time symptoms occur In most cases, the valves are calcified producing an almost complete loss of flexibility and because of this a completely satisfactory repair may be impossible unless the valve is actually taken out and *replaced with a new one The second important cause for surgical failure is* easier to remedy It is a failure resulting from use of a closed operative technique in contrast to an open one Currently employed blind operations may fail to achieve even the modest objective of opening the fused commissures accurately and widely Often only one of the three major commissures is opened, although the body of a cusp may be torn in addition, thus producing insufficiency

If, short of complete valve replacement, accurate separation of the adherent cusps is the best operation, this will probably have to be accomplished under direct vision It is becoming clear that a number of cardiac defects such as atrial septal defects,[9, 17] pulmonary stenosis,[18] ventricular septal defects,[5, 1] as well as rarer defects like triatrial heart, total anomalous pulmonary venous drainage,[11] and aortic septal defects[15] can be repaired better under direct vision than with blind techniques or only under direct vision, perhaps aortic stenosis should be added to this group

With this idea in mind, we pursued the problem experimentally and after satisfying ourselves that direct operations on the aortic valve were feasible, we have used the method in a few clinical cases[10] Hypothermia has been employed

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*Now at Northwestern University Chicago Ill anesthetic induction with Pentothal and a curare-type drug and intratracheal intubation, the patient is attached to an automatic respirator. This respirator consists of inspiratory and expiratory solenoid valves which are controlled by an electronic timing circuit (Fig. 1). It employs an open system rather than the more common circle absorption system. The respirator is set at a rate of 13 to 14 per minute and this rate is maintained. Pressure during inspiration rises to about 20 mm. of mercury and the minute respiratory volume is usually 12 to 15 L. for adults. A mixture of 5 per cent carbon dioxide in oxygen is given from the beginning of cooling until late in the rewarming period. The use of such a mixture prevents the respiratory alkalosis which occurs if oxygen alone is used with this respiratory system and, with the automatic respirator, rapid changes in blood pH, which are apt to occur with a manual respiratory system, are avoided.

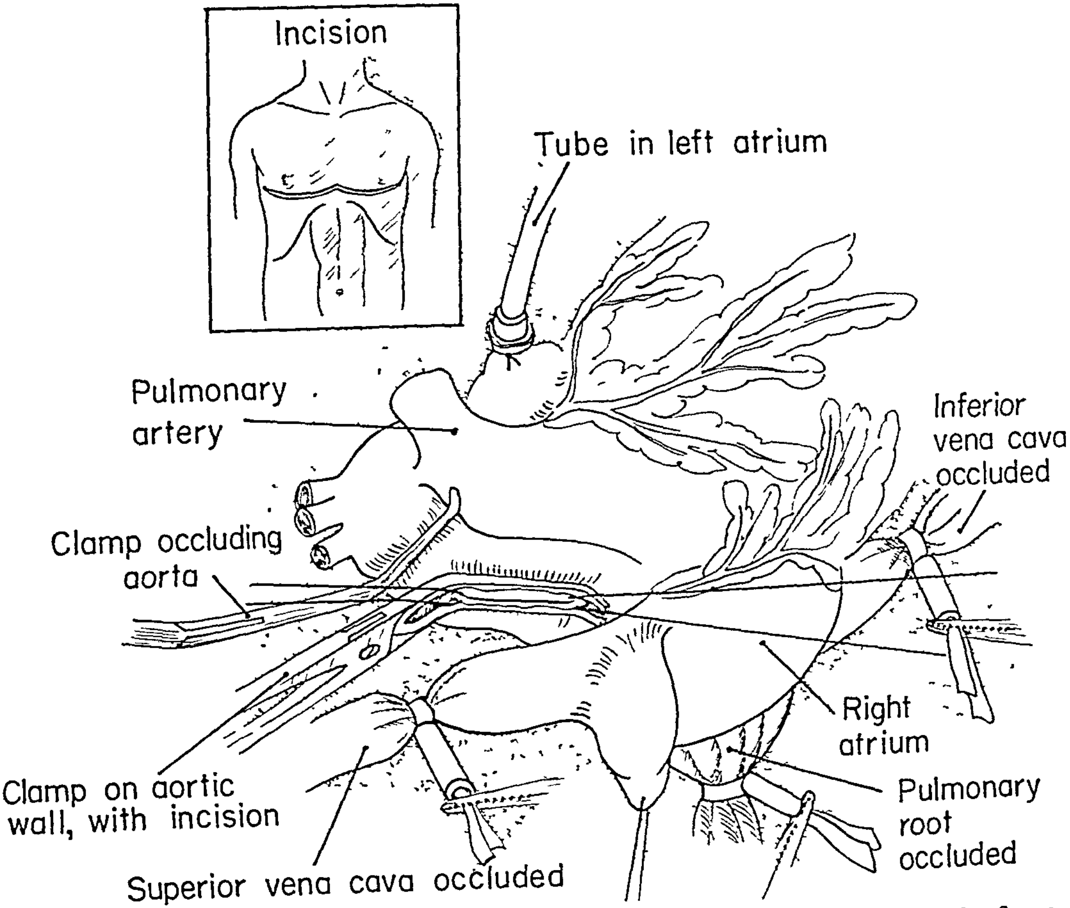

Fig 2.—The inset shows the position of the chest incision. The remainder of the figure, as well as Figs 3 through 5, is oriented with the patient's head to your left. Preparations have been completed and the aorta is about to be entered by opening the Beck clamp. There is a tube in the left atrium, and the venae cavae, pulmonary roots, and the aorta, distal to the aortotomy, have all been occluded.

Refrigerating blankets at a temperature of about −4° C. are used for cooling. Surgery is started when the body temperature falls to 30° to 31° C. but the temperature continues to fall, reaching a low point of 28° to 29° C. This low point is slightly higher than we used earlier. The electrocardiograph tracing is followed continuously on an oscilloscope and blood pH determinations are taken occasionally throughout the procedure. An intra-arterial needle or cannula is used for continuous blood pressure determination.

Fig. 2 illustrates the chest incision. The sternum is divided transversely to allow entry into both pleural cavities through the third interspaces. Loops of tape are placed around both lung roots and then with the pericardium opened widely, tapes are placed around both venae cavae. A small catheter is inserted into the left atrium through the atrial appendage in order to wash air out of the left heart at the end of the open operation.

After infiltrating the tissues around the base of the aorta with procaine, the ascending aorta is cleared. Fat and adventitial tissue are removed proximally, while the right atrial appendage is retracted, far enough to expose the origin of the right coronary artery. Distally, the ascending aorta is freed from the pulmonary artery so that it may be occluded separately. Fine stay sutures (No. 5-0 silk) are placed in the ascending aorta to mark each end of the aortotomy and a Beck clamp (Potts' principle)* is closed beneath the stay sutures to separate a generous lip of the ascending aorta. This clamp appears to be identical to the one described by Clowes[1] which he has employed for the same purpose. As a final step in preparation, the aortotomy incision is made in the lip of aorta held by the Beck clamp (Fig. 2). In this way, no time will be spent in making an incision once the inflow has been occluded.

The steps that are followed after occlusion of the cardiac inflow must be carried out efficiently and without confusion. We have employed a check list enumerating each task in proper order and this list is finally reviewed just before occluding the cardiac inflow. It might be better to have an assistant call off each item on the list as the open operation proceeds. Directly after occluding both venae cavae the respirator is turned off and the loops around both pulmonary roots are tightened in order to occlude the pulmonary veins. After a few heartbeats, a Satinsky clamp is used to occlude the ascending aorta just proximal to the innominate artery and then the aorta is opened by simply removing the Beck clamp. Blood still in the aorta is evacuated by suction to expose the aortic valve (Fig. 3). Following a careful inspection to identify the commissures, each commissure is opened out to the aortic wall. For this we use a knife and a heavy Mayo scissors. We have not tried to remove the calcium from a calcified valve cusp, for a study of pathologic specimens will show that this is impossible without partially destroying the valve, thus producing an insufficiency. After the commissures have been opened satisfactorily, a finger may be passed down into the left ventricle to check the size of the orifice.

Now, in order to close the aorta without leaving air in the left heart the following important tasks are carried out in sequence. The venae cavae and pulmonary roots are released. (We have occluded the pulmonary roots as well as the venae cavae assuming that some blood would thus be dammed up in the lungs to flow out suddenly into the left atrium at this time and thereby help wash out the air.) The fine sutures at either end of the aortic wound are

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*Manufactured by B. Richter, 843 Duane Street, Glen

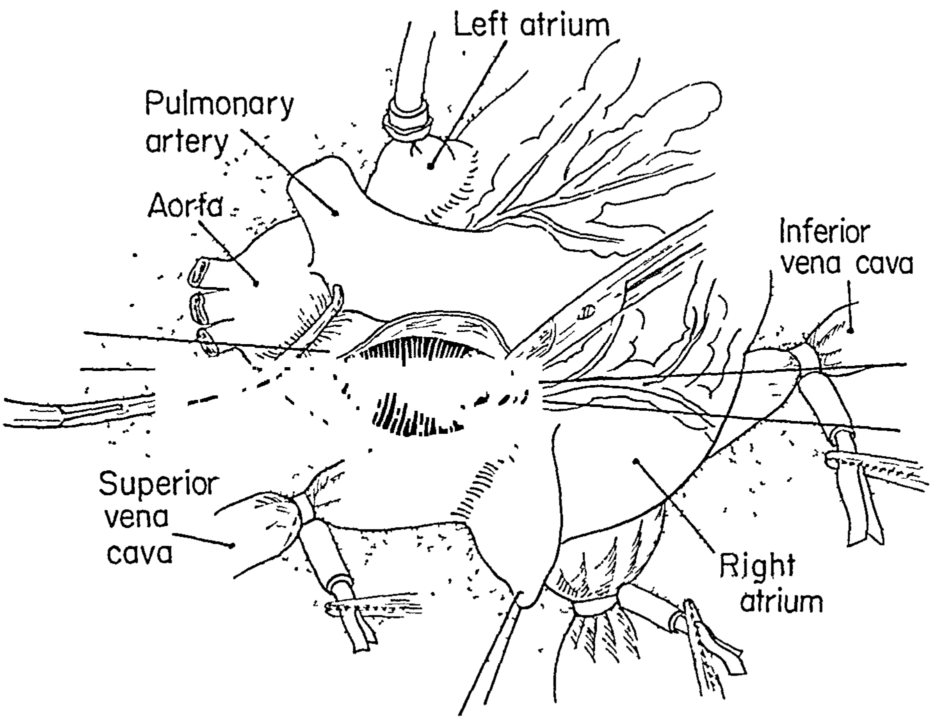


FIG. 3 —With the aorta opened the stenosed aortic valve is exposed and the fused cusps are being separated with a scissors

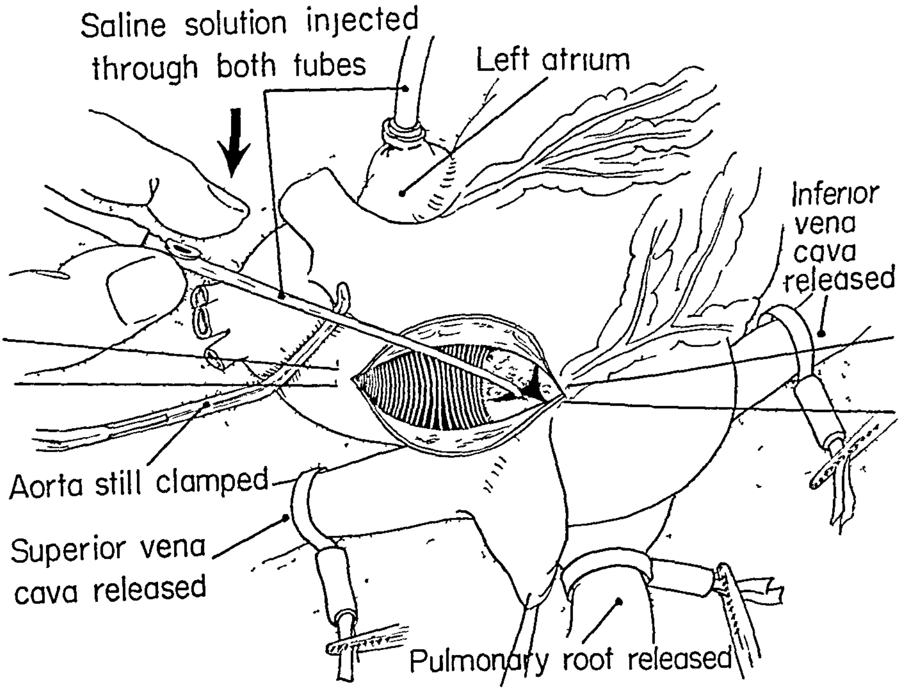

Saline solution injected through both tubes
Left atrium
Inferior vena cava released
Aorta still clamped
Superior vena cava released
Pulmonary root released

FIG 4 —In order to evacuate the air in the left heart, blood flow has been restarted by releasing both the pulmonary roots and the venae cavae In addition, the left heart is flooded with saline solution injected by way of the atrial catheter and through a tube passing down past the aortic valve into the ventricle. The distal aortic clamp is still closed

elevated and the Beck clamp is placed behind them, ready to close the wound. As this is being done, saline solution is injected under pressure through the catheter in the left atrium, and a small metal tube is passed down through the aortotomy, the aortic valve, and into the left ventricle, to inject more saline solution into the air-filled left heart (Fig. 4). Within a few moments a large gush of blood, saline solution, and air comes out through the aortic incision, and when three or four satisfactory heartbeats have each pumped out air-free fluid, the aortic incision is closed with the Beck clamp and the distal aortic clamp is released The respirator is then restarted. To keep the field clear for accurate closure of the aortic wound, two suction tips are employed. Once circulation has been resumed, the aortic wound is sutured distal to the clamp with a continuous stitch of No. 5-0 silk (Fig. 5). In the first patient, the mitral valve was explored from the right in the manner described by Bailey,[2] after the aorta had been closed.

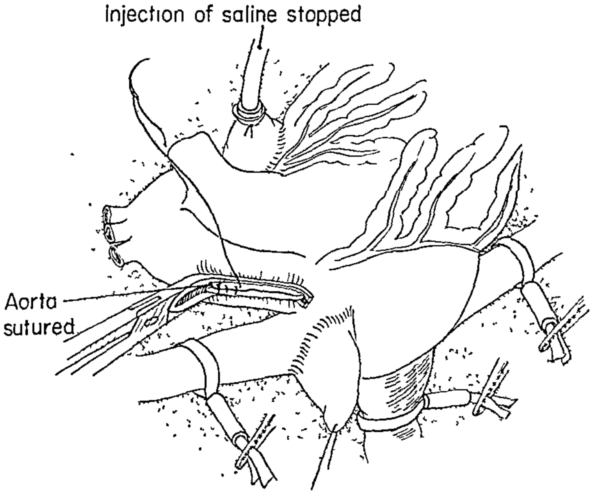
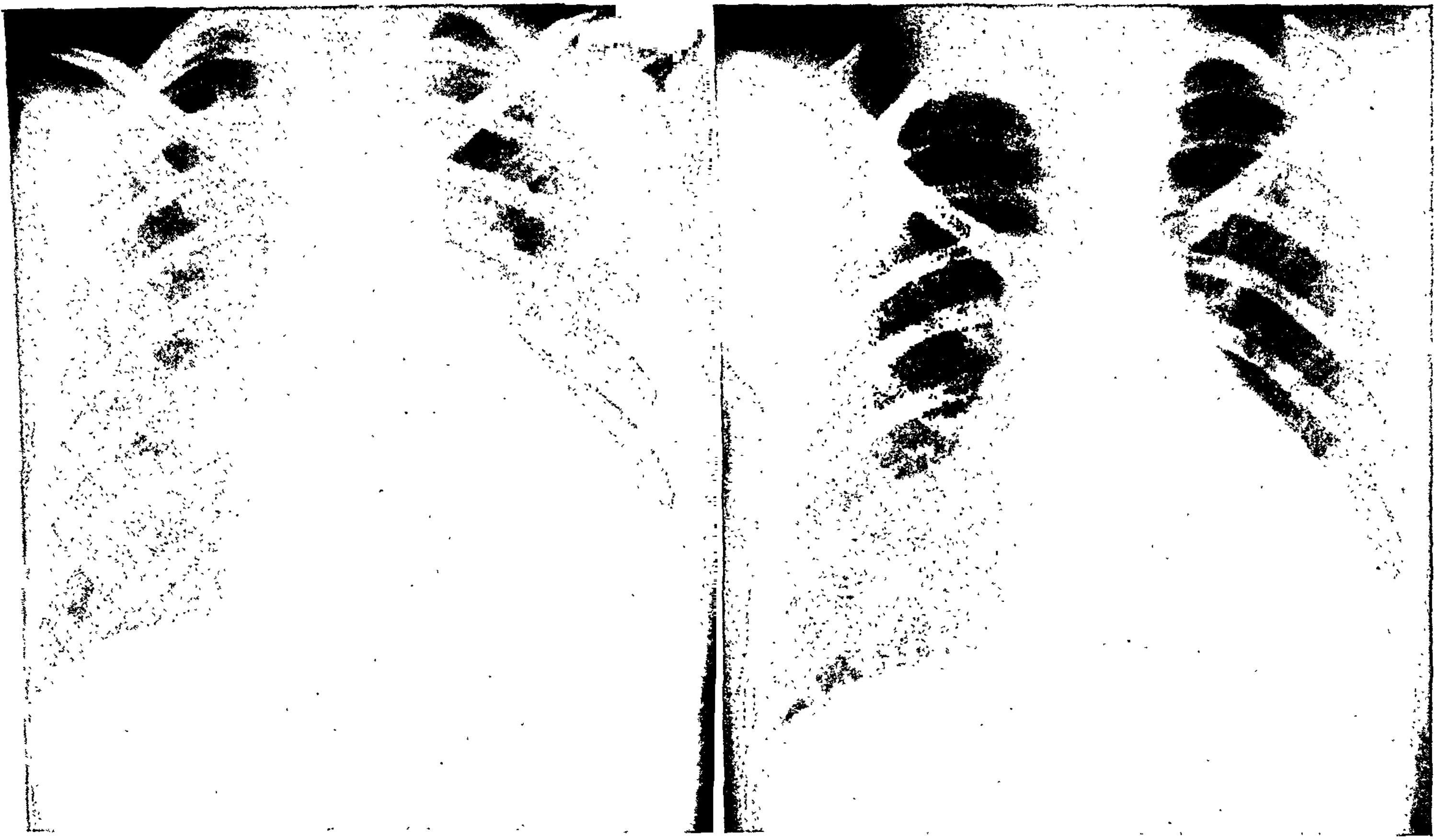


Fig 5.—With circulation resumed, the aortic wound is sutured over the Beck clamp

The operation is completed by placing chest catheters in both pleural cavities, closing the pericardium loosely, and repairing the chest wound. Three double strands of heavy, twisted, stainless steel wire hold the divided sternum but pericostal sutures of heavy catgut on either side also help to strengthen this repair.

Rewarming is commenced during the thoracotomy by pumping a warm solution through the blankets which remain under the patient and around the lower body, but the body temperature will still be low at the end of the operation so the patient is transferred to a tank of water heated to 45° C. As the



A.

B.

Fig. 6.—Chest x-rays taken immediately before surgery (*A*), and 2½ months after surgery (*B*), in Case 1. The heart has shrunk more here than would be expected following surgery in most cases of aortic stenosis.

body temperature rises, the mixture given by the respirator is changed from carbon dioxide and oxygen to oxygen alone, and finally the respirator is disconnected Rewarming is stopped when the body temperature reaches 33° to 35° C Usually the patient has spent thirty to sixty minutes in the tank

CASE REPORTS

CASE 1—This 12 year old girl (U H No 890924) was known to have a heart murmur since the age of 2½, but it was not until eight months prior to surgery that she had serious difficulty At that time she suffered several fainting episodes and chest x rays showed that her heart had become larger Despite medical treatment, her condition deteriorated until she was bedridden with chronic congestive heart failure

On examination she had a systolic murmur at the base with systolic and diastolic murmurs at the apex of the heart as well The blood pressure was 90/80 mm Hg The heart was large (Fig 6, A) and the liver was palpable and tender 8 cm below the costal margin There was minimal ankle edema

Despite her grave condition, surgery was recommended and carried out on Dec 2, 1955 Her temperature fell to a low point of 26 5° C and the operation just described was completed without complications The cusps of the aortic valve were fused to allow only a tiny opening but separation was easy with a knife because the valve was not calcified Circulation was interrupted for five and three quarters minutes After closing the aorta, the mitral valve was explored from the right, but although there was a small regurgitant jet, we felt that this was a relative insufficiency due to the large size of the heart rather than one due to intrinsic disease of the mitral valve

Her convalescence was marred by a period of hallucinations on the fifth postoperative day which lasted two or three days Choreiform motions also appeared at this time and they persisted, gradually diminishing, for two to three weeks Otherwise she has shown striking improvement as is suggested by the pre and postoperative chest x rays (Fig 6) Her blood pressure is 96/60 mm Hg She is active and is gaining weight and strength

CASE 2—A N (U H No 982278) was a 53 year old man who had suffered several fainting spells, brought on by physical exertion during the year prior to his operation He fell, breaking some teeth, during an attack and was hospitalized with the tentative diagnosis of acute coronary occlusion On examination he had a harsh murmur and a thrill over the aortic area Blood pressure was 108/86 mm Hg On x ray examination the heart was of normal size but calcification could be seen in the region of the aortic valve

The operation was performed without difficulty, according to the technique just described, on Jan 31, 1956 The aortic valve was stenosed and rather heavily calcified along the site where the cusps had fused These cusps were separated with a knife and scissors but, at one commissure, the separation was not carried entirely out to the aortic wall because we feared that too much regurgitation would be produced After finishing, the index finger could be passed back into the ventricle with ease but the valve cusps remained stiff The lowest body temperature during surgery was 29 5° C and the circulation was occluded for four minutes

His immediate postoperative recovery was uneventful He is gradually gaining strength and he has had no fainting spells since surgery but there has not been the striking improvement that characterized the first case Blood pressure is 120/80 mm Hg

CASE 3—This patient (Hosp No X 130082) was a 58 year old man who had suffered from attacks of angina for three or four years These attacks were becoming more frequent and more severe and he was also troubled with intermittent claudication On examination there was a thrill and a harsh systolic murmur over the aortic area which was transmitted to the neck bilaterally There was a diastolic murmur over the apex Blood pressure was 110/90 mm Hg The x rays showed some prominence of the left ventricle and calcification in the aortic area

SUMMARY

1. This article describes the technique of an operation for relieving aortic stenosis under direct vision during hypothermia as well as the experimental work that preceeded use of this operation on man.

2. The experimental work showed that open operations could be done on the aortic valve with a low mortality rate and that it was possible to avoid air embolism by thoroughly washing out the left heart before closing the aorta.

3. The accurate separation of all three cusps achieved under direct vision should make this a better operation than blind transventricular or transaortic operations. Nevertheless, for the heavily calcified valve a completely satisfactory result will probably require replacement with a new valve.

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DISCUSSION

DR. HENRY SWAN, II, Denver, Colo.—I should like to say a few words to reinforce Dr. Lewis' comments with regard to the value of the open approach to the aortic valve.

We have had a very limited experience so far with this, being confined to 2 patients. One of these had acquired disease and the other was a child with congenital valvular stenosis. We were quite worried, of course, about the problem of air embolism. It boils down to two aspects. If the aorta is open and the coronary ostia are exposed to the air, will air move in to the coronary arteries? It interested me that it took a long time in the history of medicine to make the crucial experiment, namely, open the aorta and see if it would move in. I think Dr. Clowes was the first to do this, and the answer is that it does not. One can sit and watch the air blood interface at the mouth of the coronary artery and there is no tendency for air to enter the coronary arteries. The position of the patient is such that the left pulmonary ostium is directly down while the right coronary is directly up. I think this is desirable because if air should enter a coronary artery it will enter the right, in all probability, because of this position and this can be seen immediately and appropriate measures taken should it occur.

The other problem is how to avoid trapping air in the left heart and in the aorta. Dr. Lewis has explained how he has avoided this. We have one slide I would like to show. We have not used Ringer's or saline solution, but we do put a multitude of clamps on, and the one to which I would particularly direct your attention is a large tourniquet around the lung roots. We also put a clamp across the innominate and carotid in case a little bubble of air got caught; this clamp comes off last to avoid any possibility of cerebral air embolus. There is also a clamp across the aorta. The area above the valve is opened and one can look down and get a view of the valve. The value of lung tourniquets is that one can trap enough blood in the lung to fill up the left side of the heart. Thus, the first escape maneuver is to release the tourniquet on one of the lung roots allowing the venous flow to come to the left auricle, fill the left ventricle and then start to move out of the incision. At this point, when the aorta appears completely full, the compression clamp is applied to the incision and the aortic clamp, as Dr. Lewis said, is very rapidly removed.

I think the great value of this procedure will prove to be in treatment of the congenital valve. The one valve we have had a chance to see at operation was quite similar to that which one sees in the pulmonary valve. By very careful placing of the incisions in the exact line of the commissures it was possible to completely relieve the stenosis and at the same time not create any regurgitation. I also understand that Dr. Glen Morrow has had the opportunity to treat one patient in this fashion with subaortic stenosis and was quite pleased with the procedure. I agree, then, wholeheartedly with Dr. Lewis that although the ideal operation for the calcific valve remains to be elaborated, this approach is very practical.

DR. DWIGHT E. HARKEN, Boston, Mass.—Dr. Lewis' paper is up to his own high standards and those of the fine group from whence he comes.

It is better to see, than to feel, and better to feel than not to feel. However, this platitude of "seeing being better than feeling," must be interpreted in the light of the cost, the risk, and the quality of what we do while we see.

We are not arguing over the congenital noncalcific valve. These probably can best be handled by open techniques. However, this may not be necessary in the adult's acquired, noncalcific, aortic stenosis. The lightly fused tricuspid aortic valve may best be managed by finger fracture.

I would like to elaborate on the difference between seeing and feeling, however, in two extenuating dimensions.

The first is the factor of *time*. These comments are based on more than seventy aortic operations. We are mainly concerned with calcific valves in the adult group. We must think in terms of the time we have to work. It may be important to work deliberately 20 or 30 minutes, and thus perhaps accomplish more than we could accomplish during a hasty open procedure under hypothermia. With a pump oxygenator, the situation may well be different. The second dimension is the *pathologic process*. We return to the fact that in the noncalcific acquired stenosis in adults, open not necessary. The tricuspid form of aortic stenosis is quite easily managed and manipulated with the finger. The spectrum ranges from the simple to the virtually impossible by any technique. "Impossible calcific barrier" is admittedly a *relative* term, depending on the surgeon and his experience.

When we palpate the valve and fracture it cautiously and, deliberatively using all the time we need, we use an Ivalon sponge operating tunnel at the aortic base. This differs significantly from the tunnel suggested by Dr. William Kirk Swann who uses a cloth tunnel.

The commissure must be opened and mobilized. These leaflets must constitute a valve that is as competent as we can make it and that represents minimal gradient to the transfer of blood.

There are those valves that we cannot correct satisfactorily with our fingers or a valvulotome by open or closed techniques. For this reason, we must address ourselves to the matter of *replacing valves.* Open techniques will be important in such replacement. Until this time, there is a useful place for operating tunnels.

I hope that by the time we meet again, we will have a competent permanent, nongradient valve, that does not propagate emboli.

DR. GERONIMO N. GUASTAVINO, Buenos Aires, Argentina.—I have enjoyed this interesting paper very much. With the object of overcoming some of the problems of aortic stenosis surgery, an instrument has been devised to be used in the aortic approach.

(slide) This is a long plastic prism, with one surface wider than the others, which carries a sliding mechanism with two acting sharp members which can be protruded closed, under visual control, through the stenotic opening.

(slide) The triangular shape of the instrument may be seen. The instrument is introduced through the aortic approach; both blades are opened after introduction through the stenotic opening. Each blade may be open or shut separately permitting individual section of any commissure; if necessary one blade may section for a greater length than the other. When the sliding mechanism is drawn back the blade cuts from below upward.

(slide) This shows the blades introduced through the stenotic opening of a pulmonary valve. The illustration was prepared on a specimen of valvular pulmonic stenosis. Next you see the nature and extent of the section of the stenotic valve produced when the sliding mechanism of the instrument was withdrawn; notice particularly how the valve is cut as the blade comes from below.

Anatomic results are similar in the case of aortic stenosis. As you know, congenital aortic stenosis resembles anatomically pulmonary valve stenosis.

(slide) When necessary, as in calcific aortic stenosis, both blades may be replaced by another sliding mechanism which carries a guillotine knife for use in very firm valves.

We believe that this instrument may permit (1) visual control of the aortic valve and stenotic opening from above; (2) introduction under visual control of two sharp acting members into the stenotic opening; (3) section of the commissures from below upward, the result of which can be visually controlled and, if necessary, the acting members may be reintroduced to make as many sections as are necessary; and (4) the triangular shape of the instrument produces minimal obstruction of the aortic lumen and permits introduction of a catheter for transfusion if necessary.

DR. HENRY B. LARZELERE, Toledo, Ohio.—Ever since the initial efforts of Horace Smithy, we have looked for the successful means whereby aortic stenosis may be treated. Digital and instrumental efforts via the left ventricle have produced results which most surgeons have decried and abandoned as too dangerous and too inconclusive. Into the "arena," labeled *experimental* surgery, have been placed more recent efforts via the aorta itself, namely, the transaortic retrograde procedures. All agree that the latter approach produces less heart strain; in other words, rarely cardiac arrest or fibrillation. Yet the dangers of hemorrhage and embolization still seem to make the risk out of all proportion to the expectations Within the past year, attack under direct vision has met with some success Reports today are very interesting and provide again great expectations We are all enthusiastic about these promises and evident results, as shown today by Dr Lewis

However, there remains the need for much more refinement and re evaluation on the part of thoracic surgeons before the surgery of this valve is shelved or relegated entirely to direct vision efforts Indeed, the patient with aortic stenosis cannot wait out his turn for certain highly specialized teams to treat his valve He must be treated or die As we all know, when the symptoms of aortic stenosis border on or become, those of congestive heart failure, the patient generally is faced with only six to eighteen months of life expectancy Therefore, an instrument and a technique for the proper treatment must be perfected to allow all patients with this disease a chance for extended life

Such means are available, but these means must be perfected Most previous instruments are quite inadequate and too cumbersome We wish to present for the first medical showing the vastly improved Donaldson instrument, and to re define the problem of aortic stenosis surgery We wish to re establish the true worth of the aortic retrograde technique

Hemostasis and actual valve commissurotomy are the two features to be emphasized For adequate hemostasis several devices are good We have come to use the plastic tunnel devised by Swan although, when available, we prefer the pericardial homograft pouch method of Bailey To effect the best hemostasis in the use of either tunnels or pouches, not necessary. The tricuspid form of aortic stenosis is quite easily managed and manipulated with the finger. The spectrum ranges from the simple to the virtually impossible by any technique. "Impossible calcific barrier" is admittedly a *relative* term, depending on the surgeon and his experience.

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Experience has shown that approximately half of the stenotic aortic valves can be adequately opened by digital technique alone. However, in the remaining cases, careful and constantly guided instrumentation is essential. For the calcific valve, loaded with granular or pedunculated calcium deposits, it seems brutal to assume that blunt digital efforts, with the inherent risk of embolization, are to be accepted. In such cases a shearing positive force, applied simultaneously to all the diseased commissures, is necessary. In this way embolization is kept to a minimum.

The Donaldson instrument very capably achieves this goal; and as a dilator has been used many times successfully at several centers. However, too often, momentary short cuts in its use have caused fatalities. Each "pass" or engagement of the instrument into the valve orifice must be guided. Completely blind maneuver without finger-tip control leads to embolization, torn valve cusps, blocked or damaged coronary orifices, and disruption of hemostatic control. Dr. Samson has been kind enough to aid me in presenting a silhouette of this thin-shafted, rugged, all stainless steel instrument. Guided instrumental engagement is made easy by placing the instrument along the palmar aspect of the finger. The finger tip is made to "seat" carefully into the sinus of Valsalva; the instrument is then engaged, and the commissurotomy is effected. The instrument may well have its greatest place in the open surgery on the aortic valve, as well as in the so-called closed maneuver.*

DR. CHARLES P. BAILEY, Philadelphia, Pa.—Of course you understand that we are very fond of Dr. Lewis and he of us. Otherwise, he probably would not have picked on Philadelphia so much. Speaking of priorities, he raised the question: I performed the first historic open heart operation for an atrial septal defect under hypothermia four days before he did (Aug. 29, 1952). The difference was that my patient died while his lived. Maybe that experience gave me a more dismal view of hypothermia than he and Dr. Swan have come to accept. John Gibbon of Philadelphia was the first in this country, and perhaps in the world, successfully to open a heart with the use of a heart-lung machine.

During the past six years, we have operated upon a total of about 450 patients with aortic stenosis. A few of the early procedures now seem pretty antiquated. We performed over 200 transventricular dilatations of the aortic valve and operated on another 200 by the supravalvular route. We now insist on a tricommissural opening in every normally formed valve or else we consider the operation a failure; the mortality in the transaortic procedure is about 15 per cent. Recently, hearing that Dr. Lillehei had opened one of these valves under direct vision with a pump and oxygenator, we have decided to do likewise in certain cases and now have operated upon 2 patients using the Friedland-Gemeinhardt bubble-type oxygenator. We used the Blanco, Adam, and Fernandez method of cannulating the coronary sinus for retrograde perfusion of the myocardial capillary bed which Dr. Lillehei has used also. One patient was a 14-year-old boy with congenital aortic stenosis and subaortic stenosis. The other was a 24-year-old man with what proved to be an acquired and calcific type of aortic valvular stenosis. The method worked very nicely. In both cases, we were able to obtain the same good tricommissural opening that we have come to expect with the closed method. In both we abolished the gradient as we should have expected with the closed method. No regurgitation was produced. We took 16 and 24 minutes, respectively, for the definitive surgery. I must point out, however, that while the open approach would seem to be very useful in congenital aortic valvular disease in which the commissures might not be normally formed and also in calcific aortic stenosis since there is danger that a fragment might be dislodged, each of these procedures took us more than 7 hours and we had to sit up with the patients afterward to be sure they did not bleed to death or something like that. We are inclined to think that the usual 3 hour operation by the closed technique might have many practical advantages in some of these patients. However, this is a wonderful presentation of a fine new approach in certain of these cases. Unquestionably, open surgery for aortic stenosis is here to stay.

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*It is contrary to the policy of this JOURNAL to publish illustrations with the discussion. However, an exception has been made in this case, both because it is easier for the reader to get a clear idea of the instrument by seeing photographs of it, and because of the Editor's desire to give all possible assistance to the development of this very important new field of operative surgery.—EDITOR.

DR. C. W. LILLEHEI, Minneapolis, Minn.—I would like to supplement Dr. Lewis' fine presentation by describing yet another method for extending the benefits of direct vision reparative surgery to the aortic valve and other left heart lesions.

The ready availability of a simple, straightforward, and effective pump oxygenator for human use has shifted the emphasis upon research in our experimental laboratory from that of the development of methods for open cardiotomy which occupied our attention for so long, to that of application of the advantages of open cardiotomy to the treatment of various cardiac lesions likely to benefit by this approach. As a result, about a year ago the problem of working upon the left heart commenced in the experimental laboratory. In working in this area in an unhurried manner there are at least two obstacles that need to be overcome. One is the prevention of coronary air embolism, the other is the maintenance of some coronary blood flow to the myocardium to prevent muscle hypoxia.

It may be suggested that direct vision reparative procedures upon the aortic valve be carried out rapidly enough to allow their completion during a brief interval without coronary blood flow. While this is certainly possible, we have rejected this approach for two reasons. First, a time limitation is imposed which is undesirable for the patient. Second, however short the procedure can be made, the myocardium at the end of such an interval is left in a hypoxic state. This is also true when selective cardiac arrest without coronary circulation is induced. In critically ill patients, this metabolic oxygen debt within the cardiac muscle could be intolerable and vitiate an otherwise successful surgical procedure. The same considerations in some measure pertain to the use of hypothermia and temporary arrest of the circulation for exposure of the aortic valve.

The method that we have used to avoid these obstacles has been to totally by-pass the heart and lungs in the usual fashion with the pump oxygenator and to retroperfuse the coronary venous system with oxygenated blood through a separate catheter inserted into the orifice of the coronary sinus. Pratt, in 1898, first pointed out that the myocardium could be nourished in this fashion. Drs. Blanco, Adam and Raffucci from the department of surgery at the School of Tropical Medicine in San Juan, Puerto Rico, have reported on experiments applying these observations. Likewise Beck has made use of this principle in his revascularization procedures. However, I might emphasize one important difference in utilization of this principle for open heart surgery, that is, with the ascending aorta open (and the pressure within, zero) the resistance to retrograde flow through the coronary system is slight and adequate flow occurs with a very low pressure. In the clinical cases, we have pumped only enough blood into the coronary sinus to maintain a healthy pink color in the myocardium and this amounts to a mere trickle since the oxygen requirements of the nonworking heart are low.

In our experimental laboratory, Dr. Gott has consistently maintained the hearts of dogs on retrograde coronary sinus perfusion with the aorta open for 30 minutes with only an occasional instance of arrhythmia. I might mention that the nonworking canine heart usually fibrillates or arrests in far less time when the coronary circulation is cut off completely.

Clinically we have utilized total by-pass of the heart and lungs with retroperfusion of the coronary sinus in patients with five different types of pathology involving the left side of the heart. In each case, the human heart remained a healthy pink color and continued to beat at a slow regular rate throughout the interval of maintenance by retroperfusion.

The first patient, a 38-year-old woman with calcific aortic stenosis, was operated on in January, 1956.

(Slide) This is her preoperative chest x-ray showing the large amount of calcium in the aortic valve. Physically, she was in Class IV, being completely incapacitated. This type of case has given rather discouraging results when managed by closed methods. This lady's aortic valve was exposed to direct vision for 11¼ minutes while the cusps were mobilized accurately at their commissural junctions, and some of the verrucous calcium deposits trimmed off the leaflets. There were no arrhythmias and her postoperative improvement has been dramatic, and sustained to date.

(Slide) In a 7-month-old infant with an aortic pulmonary septal defect, this technique allowed us to simply divide the fistulous communication between the empty ascending aorta and main pulmonary artery, and oversew the open ends. In this case, the heart was supported by retrograde coronary sinus perfusion for 7 minutes without arrhythmias. The infant died ten days later of a diffuse bronchiolitis probably aggravated by the severe pulmonary hypertension present preoperatively. However, this approach converted what is often an impossible dissection by closed methods into a simple open procedure.

(Slide) The third patient, 10 years of age, had a ruptured sinus of Valsalva into the right ventricle. Her blood pressure prior to corrective surgery was consistently 110/0 mm. Hg. After the heart and ascending aorta were rendered bloodless by this technique, the defect was closed with interrupted silk stitches placed under direct vision. Immediately following corrective surgery, she had a diastolic pressure of 70 mm. Hg and convalescence was uncomplicated.

Two other types of lesions have been managed in this fashion. Multivalvular (aortic regurgitation, mitral stenosis) rheumatic heart disease in a 52-year-old patient treated successfully by direct vision aortotomy and left atrial cardiotomy; and in a 15-month-old baby with complete transposition of the great vessels, both coronary arteries were moved with the aorta to the left (posterior) ventricle, the pulmonary artery was joined to the right (anterior) ventricle, and multiple ventricular defects were closed. This latter patient died in the postoperative interval but the heart was maintained without arrhythmia and with an excellent beat and color for 16 minutes while the coronary arteries and aortic valve were anastomosed to the posterior ventricle.

In conclusion, this experience has suggested that this method is a valuable adjunct to the pump-oxygenator for left heart surgery. Further, if one lets his imagination wander for a moment several other applications are apparent, such as replacing the ascending aorta for aneurysms or to permit the cross-clamping of the main coronary arteries for a temporary period to allow direct surgical procedures upon these vessels.

DR. WILLIAM H. MULLER, JR., Charlottesville, Va.—I, too, would like to congratulate Dr. Lewis on this excellent accomplishment, but I would also like to raise the question of the advantages offered by the open procedure over those offered by the closed procedures that are now utilized for acquired aortic stenosis. I would agree with those who say that the open technique for congenital aortic stenosis is better because one has a more normal valve to open. The aortic valve in acquired aortic stenosis is often so deformed and calcified that residual commissural fusion lines are not discernible. Actually, the goal in opening the aortic valve is to relieve the gradient across it and this can be done in almost all instances with either the transventricular or the retrograde approach. I think we will probably continue to use these outmoded procedures until the valve can be replaced with a satisfactory prosthesis.

DR. J. H. KAY, Bethesda, Md.—Drs. Kaiser, Gaertner, and I have used a similar method experimentally as well as clinically. Eleven dogs were cooled to a final rectal temperature of 32° C. and a right anterior thoracotomy was performed through the fourth intercostal space. The base of the aorta was exposed on the right side at the origin of the aortic valves by retracting the right auricular appendage caudad After performing inflow occlusion the aorta was cross clamped at the origin of the great vessels The base of the aorta was then opened for 4 minutes This gave excellent exposure of the aortic valves The caval ties were released and all the air flushed from the left ventricle and aorta The incision in the aorta was clamped and the clamp used for cross clamping the aorta was removed There was no evidence of cerebral, coronary, or peripheral emboli All 11 dogs were chronic survivors We then operated on the following 2 patients with Dr Morrow Using a bilateral anterior incision as described by Dr Lewis, the open approach was used to cut the stenotic aortic valve in a very ill, middle aged woman Because of mitral stenosis, a mitral commissurotomy was also done Although this patient was alert and awake postoperatively, she died five days later of a pulmonary embolus The second patient had a subvalvular aortic stenosis that was satisfactorily treated with the open approach A median sternotomy was used in this patient It gave excellent exposure We feel that the postoperative period will be much easier for patients with a median sternotomy than with the bilateral anterior incision We agree wholeheartedly with Dr Lewis that aortic valvotomy under direct vision is the best present day method of treating aortic stenosis

DR LEWIS (Closing) —I would like to thank the discussants for their stimulating comments It is gratifying to find so much interest in this type of surgery, and I am especially delighted to find some supporters among the group I am sure there are more among you who could have stood up to support this, for I know of a few others who have actually used the technique

If Dr Bailey were not such a gracious gentleman I am sure his response to my comments would not have been so kind I am humbled by his attitude as well as by the large number of cases he has operated on But he still leaves me rather confused as to how my priority rating stands So I think I will have to go home and put that scissors aside, in case the Smithsonian Institution does finally ask me for it

So far as Dr Lillehei's comment concerning trimming of the calcium off these valves is concerned, I would warn any of you who might want to try this, to try it in dead specimens first In our own experience this seems to be an impossible technique Usually the calcium extends to both valve surfaces and if you take out the calcium you make a hole in the valve so we do not try to trim calcium out of these calcified valves

I am sure there will always be some, like Dr Muller, who will stick to the older techniques as long as they can Any active society always has a few members who are slow to accept change Others of you I am sure will soon come to using an open technique on these cases

INDICATIONS FOR LOBECTOMY IN THE TREATMENT OF CARCINOMA OF THE LUNG

Joseph L. Robinson, M.D., John C. Jones, M.D., and B. W. Meyer, M.D.
Los Angeles, Calif.

In presenting this subject for discussion by the members of the Association, we should like to have it clearly understood that we are not raising the question of whether lobectomy is a better operation than pneumonectomy in the treatment of pulmonary carcinoma, but rather, in treating a human being for carcinoma of the lung, under what circumstances is it preferable to remove less than the entire lung? We believe that every surgeon worthy of the name must, in treating a given patient, temper the zeal of the surgical technician with the judgment of the physician within him. His aim in treating a patient must be not only to bend every effort to save the patient's life, but to do so in such a manner as to make that life as happy and satisfactory in the living as is possible. Because of the multiplicity of clinical factors which bear upon each individual patient, "indications" for surgical procedures must serve not as absolute criteria but rather as guideposts to aid the surgeon in reaching a

Until 1950, the question of lobectomy for carcinoma of the lung had not assumed serious proportions for us, and of 79 resections for carcinoma, only 3 had been lobectomies. But in late 1950 and early 1951, an attempt was made in Los Angeles County to survey by minifilm chest x-ray the entire adult population. One of the results of that survey was to bring eventually to the operating table a number of patients with small, round, circumscribed, peripheral, asymptomatic lesions whose etiology could not be determined until the tissues were placed in the hands of a pathologist. In those instances in which the pathologist reported a malignancy, our policy has been as follows: (1) if the lesion is well removed from the fissure or the adjacent lobes, and from the point of transection of the bronchus, and the mediastinal and hilar nodes do not appear to be involved, and the pathologist reports no involvement of the peribronchial lymph nodes, we are satisfied to do only a lobectomy; (2) if the above conditions are not satisfied, we proceed to do a total pneumonectomy *unless* the patient's cardiorespiratory situation contraindicates it, in which case we do not resect any more lung tissue, but do dissect out all the available lymph nodes.

The results of that policy upon our resections are shown in Table I. The proportion of lobectomies, which prior to 1950 was 3.8 per cent, jumped to 30.4 per cent in 1950, and for the past 2 years has exceeded the pneumonectomies.

TABLE I. OPERATIONS FOR PRIMARY CARCINOMA OF THE LUNG

YEAR	NUMBER OF OPERATIONS	NUMBER OF RESECTIONS	NUMBER OF PNEUMONECTOMIES	NUMBER OF LOBECTOMIES	PER CENT LOBECTOMIES
Prior to 1950	160	79	76	3	3.8
1950	36	23	16	7	30.4
1951	38	18	13	5	27.8
1952	41	24	18	6	25.0
1953	37	17	9	8	47.0
1954	38	26	11	15	57.7
1955	26	13	5	8	61.5
Total since 1950	216	121	72	49	40.5
Total	376	200	148	52	26.0

A one-year follow-up of the patients operated upon during that period (January 1, 1950 to January 1, 1955) shows (Table II) that there were 41 lobectomies, after which 21 patients, or 51 per cent, have lived one year or more, and 67 pneumonectomies, after which only 4, or 6 per cent, have lived one year or more.

TABLE II. RESECTIONS FROM JANUARY 1, 1950 TO JANUARY 1, 1955

	NUMBER RESECTED	NUMBER ALIVE ONE YEAR OR LONGER
Lobectomies	41	21—51 %
Pneumonectomies	67	4— 6 %
Total	108	25—23.2%

We do not have a sufficient number of patients to make a five-year follow-up meaningful, but reference to the mortality curve published in a previous paper, and which is shown in Fig. 1, indicates that a three-year follow-up is quite satisfactory for purposes of comparison.[7]

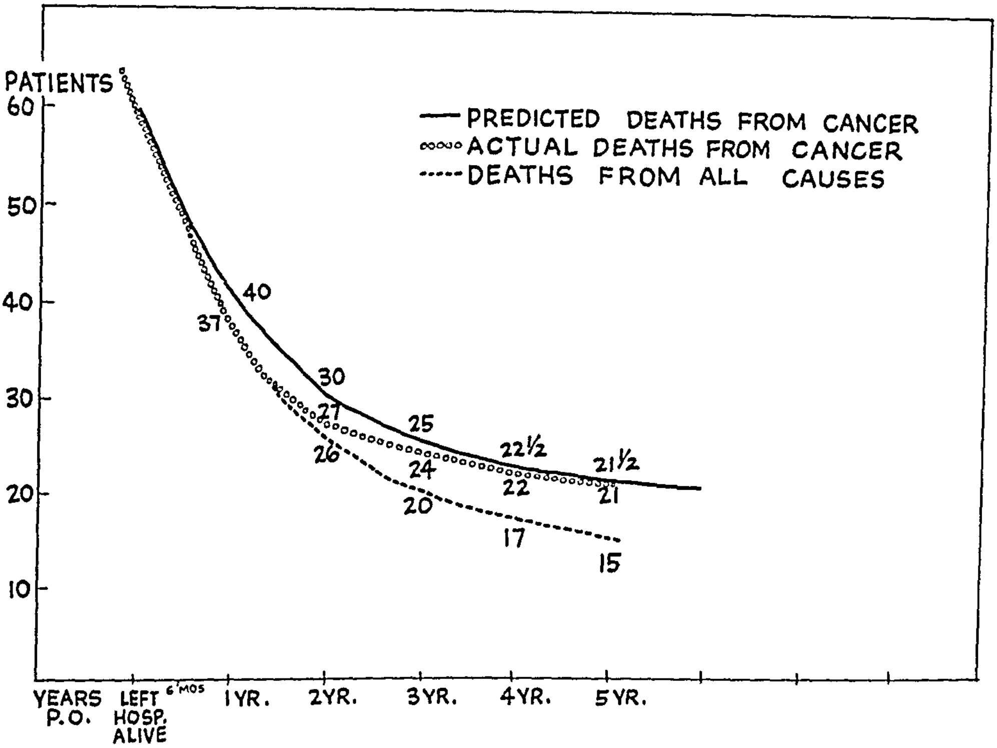

Fig. 1.—Primary bronchogenic carcinoma of the lung. Follow-up study of 64 patients five to eleven years after pulmonary resection.

Table III shows such a comparative follow-up of the lobectomies and pneumonectomies. Of 21 patients upon whom lobectomy was performed at least three years ago, 15, or 71.4 per cent, were alive at the end of the three-year period. Of 123 patients having a pneumonectomy, 20, or 16.3 per cent, were alive at the end of three years. The reason why the three-year follow-up on lobectomies appears better than the one-year follow-up is that most of the patients in the early period were patients with a peripheral, coin, or survey type lesion with a relatively good prognostic outlook, whereas later many patients were included with poor cardiorespiratory function in whom lobectomy was a compromise operation.

Table III. Resections From January 1, 1942 to January 1, 1953

	NUMBER RESECTED	NUMBER ALIVE 3 YEARS POSTOPERATIVE
Lobectomy	21	15—71.4%
Pneumonectomy	123	20—16.3%
Total	144	35—24.3%

Of course a comparison of follow-up statistics on pneumonectomy and lobectomy patients is in itself rather meaningless, since many more patients with a good prognosis will be included in the lobectomy than in the pneumonectomy group, and the survival rate is bound to be better by virtue of this selection It has been argued[6] that survival rates would be better in even the group of patients with small peripheral lesions if they were treated by pneumonectomy rather than lobectomy The only way to conclusively answer this question would be to conduct the impossible experiment of pairing a large number of patients with similar lesions, and doing lobectomy on one and pneumonectomy on the other, and since this experiment cannot be performed we must draw conclusions from other methods of study One such method is to collect the considered opinions of surgeons who are treating patients with carcinoma of the lung, and this we have attempted to do by means of a questionnaire, which is reproduced in Table IV

TABLE IV THE QUESTIONNAIRE

1 Do you perform lobectomy for carcinoma of the lung	
a For a primary carcinoma?	Yes— — No— —
b For metastatic carcinoma?	Yes— — No— —
2 If so, do you use lobectomy	
a As an operation of choice under certain conditions?	Yes— — No —
b Only in cases in which there is some contraindication to pneumonectomy?	Yes — No— —
3 Given the indications which you consider would make the operation one of choice, is it your experience that it offers the patient as good a chance for long term survival as does pneumonectomy?	Yes— — No— —
Further comments	

In making up the questionnaire which was sent to the surgeon members of the Association, we attempted to gain certain information regarding present day practice in the use of lobectomy in the treatment of cancer of the lung We wished to find out (1) to what extent lobectomy is being used in treating pulmonary carcinoma, (2) under what circumstances it is being used, for example, as an operation of choice, as a compromise operation in patients with poor cardiorespiratory function, or as a purely palliative procedure, and (3) whether it has had sufficient use to enable thoracic surgeons to form an opinion as to its efficacy as a curative procedure in treating carcinoma of the lung In addition, we hoped that we might obtain further expression of opinion on the subject, and therefore added an inviting "further comment" column to our questionnaire We have been very gratified by the response of the members of the Association, not only in the number of answers we have received (318 out of 400 sent out), but even more so by the high proportion of surgeons who made additional comments (208, or 68 4 per cent of the 304 usable returns)

TABLE V TABULATION OF ANSWERS TO QUESTIONNAIRE

	1 A	1 B	2 A	2 B	3—PER CENT
No	20	17	39	87	54— 17 8
Yes	282	279	236	123	173— 56 9
Qualified yes	0	0	2	2	25— 8 2
Unanswered	2	8	27	92	52— 17 1
Total	304	304	304	304	304—100

ANALYSIS OF REPLIES (Table V)

1. Extent of use of lobectomy in treating pulmonary carcinoma.

A. *Metastatic carcinoma:* Two hundred and seventy-nine, or 91.8 per cent, of those answering the questionnaire resect solitary metastatic pulmonary lesions. The extent of the resection is kept as small as possible, and may be a subsegment, segment, or a lobe.

B. *Primary carcinoma of the lung:* Two hundred and eighty-two, or 92.8 per cent, use lobectomy in treating primary carcinoma of the lung.

2. Under what conditions is it used?

A. *As an operation of choice:* Two hundred and thirty-six, or 77.6 per cent, perform lobectomy as an operation of choice under circumstances of their own choosing. Thirty-nine, or 12.8 per cent, do not use it as an operation of choice, and 9.6 per cent did not answer the question.

B. *As a compromise operation:* One hundred and twenty-three, or 40.5 per cent, said they use it only when there is some contraindication to pneumonectomy. There is some discrepancy here, since 77.6 per cent had said they use it as an operation of choice, but it is apparent from the comments made that the 77.6 per cent was made that large by some who referred to its use in metastatic carcinoma, and the 40.5 per cent who answered yes to B, were referring to its use only in primary carcinoma. It would appear then, that about 60 per cent of those who make use of lobectomy in treating primary carcinoma of the lung, use it as an operation of choice, and 40 per cent use it only as a compromise operation in patients they do not consider suitable for pneumonectomy.

3. Has it had sufficient use to enable thoracic surgeons to form an opinion as to its efficacy? We were somewhat surprised that only 52 surgeons, or 17.1 per cent, were of the belief that they had not had sufficient experience to justify an opinion on this question. The question asked was "Given conditions which you consider make the operation one of choice, is it your experience that it offers the patient as good a chance for long-term survival as does pneumonectomy?" One hundred and seventy-three, or 56.9 per cent, answered yes. An additional 25, or 8.2 per cent, answered yes with reservations, chiefly concerning the small number of cases they had seen. Fifty-four, or 17.8 per cent, answered no. So, of the 227 surgeons who expressed an unqualified opinion, 76 per cent, or better than 3 out of 4, believe that in properly selected patients, a lobectomy offers as good a chance for long-term survival as does a pneumonectomy.

The comments made in the replies to the questionnaire varied considerably, both as to context and as to extent; and they make very interesting reading. To a large degree they had to do with the indications for the selection of patients for lobectomy, the poor over-all experience in attempting to cure pulmonary carcinoma, the use of other means (radiation or chemical) in conjunction with resection, or the reasons why lobectomy is, or is not, a satisfactory method of attacking primary carcinoma of the lung. Of the 208 who made some comment, 81 specifically listed poor cardiorespiratory function, age, or other factors which make the patient a poor risk for pneumonectomy, as an indication for lobectomy. Seventy-eight listed a small, circumscribed, peripheral lesion as an indication for lobectomy, and 31 of these included negative lymph nodes among the criteria. Six even went so far as to say that they consider lobectomy the operation of choice whenever it is anatomically feasible. Twenty-five mentioned palliation as an indication for lobectomy. There were some other specific indications, such as the cell type and the lobular location of the lesion. Twenty-three gave various reasons why pneumonectomy is a superior operation in all cases, and of these only 3 mentioned specifically the Brock type lympho-pulmonary resection[3] as the ideal procedure.

DISCUSSION

The success or failure of surgical resection in curing carcinoma is determined by whether or not extension has occurred into tissues other than those resected. In the case of carcinoma of the lung, direct extension can usually be determined at the time of surgery. Lymphatic extension may or may not be determined. Blood stream extension or bronchogenic spread is not apparent until symptoms or signs of it appear. Factors, such as the rate of growth of the tumor, cell type, lymphatic blockage, chance, and others, are important in determining whether extension occurs early or late but once surgery is completed the die is cast. Because time is always involved in direct or lymphatic extension, it has been accepted as good surgical practice to make a wide resection of carcinomatous tissue (including en bloc resection of its lymphatics) in order to remove any microscopic extension of malignant cells into adjacent tissue or lymph channels. Those who advocate complete pneumonectomy with widespread lymph node resection are trying to apply to the lung the same technique as is applied, let us say, to carcinoma of the breast. But the lung differs quite markedly, anatomically, from the breast, particularly as regards lymphatic drainage. The question of direct extension into adjacent tissues or along the involved bronchus can usually be quickly settled by the surgeon or the pathologist at the time of surgery. But because of the widespread intercommunication of the lymph channels from the two lungs, it is questionable whether a widespread removal of the lymphatics from only one side of the mediastinum is worthwhile. Rouvière in his classical description of the lymphatics of the lung[11] had this to say, "Nodes of the tracheal bifurcation form a crossroad where lymphatic vessels which issue from the diaphragm, the heart, the cardia, the esophagus, the inferior part of the trachea, the bronchi and the lungs meet directly or by means of lymphoid relays." Others have confirmed his findings.[8, 10] The normal drainage from the left lower lobe is into the glands of the right upper mediastinum, and we are sure that most of us have seen patients in whom, following resection of a carcinoma of the left lower lobe, the earliest manifestation of recurrence has been in the glands of the right upper mediastinum. This factor of lymphatic intercommunication, together with its increased morbidity and mortality rates, has apparently prevented any large number of thoracic surgeons from adopting the so-called radical pneumonectomy as a routine procedure. Based upon comments made in replies to our questionnaire, it is apparent that a not insignificant number of surgeons have adopted the practice of doing a local resection of the lesion, whether that requires lobectomy or pneumonectomy, and then depending upon radiation or chemical means to treat any involved lymph nodes.

SUMMARY AND CONCLUSIONS

1. For the past six years in a selected group of patients, we have been making increasing use of lobectomy in our surgical attack upon primary carcinoma of the lung. Our experience to date has led us to be satisfied to continue this policy. Of 123 patients treated by pneumonectomy, the three-year survival has been 16.3 per cent, and of 21 lobectomies, the three-year survival has been 71.4 per cent.

2. A survey has been conducted among the surgeon members of The American Association for Thoracic Surgery to determine to what extent and under what conditions they are using lobectomy in treating patients with carcinoma of the lung. The results of that survey show that of 318 replying, (1) 91.8 per cent use lobectomy in treating metastatic pulmonary carcinoma, (2) 92.8 per cent use lobectomy in treating primary pulmonary carcinoma. About 60 per cent use it as an operation of choice in treating primary carcinoma of the lung. Forty per cent use it only as a compromise measure in patients whom they feel would not tolerate a pneumonectomy. (3) Of the 318 who replied, 227 surgeons believe that they have sufficient experience with lobectomy to be able to offer an unqualified opinion regarding its efficacy. Seventy-six per cent (56.9 per cent of the total replying) believe it offers as good a chance for long-term survival as does pneumonectomy, and only 24 per cent (17.8 per cent of the total) do not.

3. Based upon the replies to the questionnaire distributed to members of the Association for Thoracic Surgery, as well as upon our own experience, we suggest the following as a guide in the selection of patients with primary carcinoma of the lung to be treated by lobectomy.

A. As an operation of choice. A peripheral lesion located well away from the fissures or adjacent lobes, with a satisfactory proximal length of uninvolved bronchus, and with no apparent extension to adjacent tissues, nor to the peribronchial, hilar, or mediastinal lymph nodes.

B. As a compromise operation. In patients whose lesion does not satisfy the above conditions, but whose cardiorespiratory or other clinical condition makes them unsatisfactory subjects for total pneumonectomy.

C. As a palliative operation. In patients who, at the time of operation, are found to have a lesion which obviously cannot be completely eradicated surgically, but in whom a clinical appraisal has indicated that such symptoms as hemoptysis, cough, or infection can be controlled better by lobectomy than by nonsurgical means.

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(For Discussion, see page 517.)

COMMON FACTORS IN LUNG CANCER SURVIVORS

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EACH year more long-term lung cancer survivors are recorded. Significant numbers from a single institution have not been reported, however. A recent review of cases seen in our clinic has made possible a search for common factors in five-year survivors. Information gained from the study has aided the simplification of management procedure.

Records of 101 three-year survivors were surveyed. Fifty-five of these cases lived more than five years after pulmonary resection. None of the five-year survivors presented evidence of cancer recurrence. Thirty-three are alive now more than five years, and 17 are living now more than ten years. The remaining 5 died of other causes, from five to thirteen years after surgery. All were treated in the nineteen-year period from June 1932, to May, 1951.†

Table I. Primary Pulmonary Carcinoma
June, 1932—May, 1951

Proved histologically	733*	
Explored	457	(62%)
Resected	261	(37%)
Operative mortality	56	(12%)

*44 Adenomas excluded.

In this study, age and sex were not important factors as to survival. The patients in this group were slightly younger than the other cases seen during the same period, but age distributions were similar in the two groups (Table II).

Table II. Primary Pulmonary Carcinoma
June, 1932—May, 1951

AGE	FIVE-YEAR SURVIVORS (55) (PER CENT)	ALL OTHERS (678) (PER CENT)
Under 40	7	5
40-49	23	20
50-59	42	40
60-69	26	30
70 and over	2	5

Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

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†During this period, 733 cases of histologically verified lung cancers were observed. (Table I.) Of those 678 who did not survive five years, 402 were explored, 206 had resections, and 54 had radiotherapy. Sixty-seven of the resections were performed with hope of cure; 50 patients had regional lymph node involvement; 89 had gross extension to adjoining viscera. Over-all operative mortality was 12 per cent, including all deaths occurring within thirty days after anesthesia. During the same 1932 to 1951 period, 44 cases of bronchial adenoma were encountered. These are not included in this report. However, in Fig. 1 comparative survival rates of adenoma and cancer are shown.

The youngest five-year survivor was 24 years of age at the time of surgery, and the oldest was 70. In both groups there were seven times as many men as women (Table III).

TABLE III. PRIMARY PULMONARY CARCINOMA
JUNE, 1932—MAY, 1951

SEX	FIVE-YEAR SURVIVORS (55) (PER CENT)	ALL OTHERS (PER CENT)
Male	87	87
Female	13	13

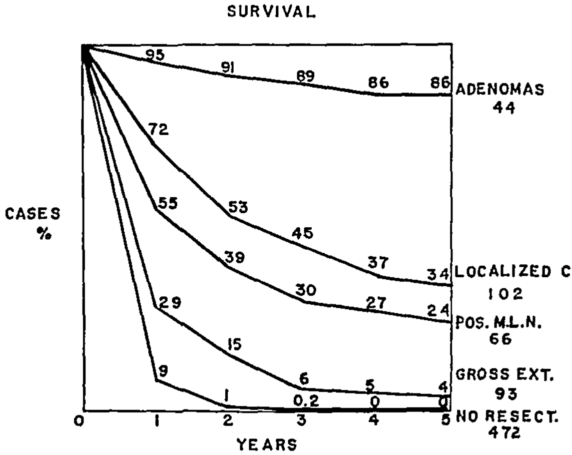

Fig. 1.

Symptoms in those who survived five or more years were not distinctive. Cough, hemoptysis, chest pain, and symptoms of respiratory infection were the most common initial manifestations (Table IV). At the time of resection,

TABLE IV. FIFTY-FIVE FIVE-YEAR SURVIVORS (SYMPTOMS)

INITIAL	SYMPTOMS	AT DIAGNOSIS
26		
7	Cough	40
7	Hemoptysis	23
7	Chest pain	15
7	Respiratory infection	12
6	Systemic	14
3	Dyspnea	5
	Wheeze	

all but 5 of the 55 patients had pulmonary symptoms. In addition, 13 had systemic symptoms of weight loss, anorexia, malaise, or fatigue. One patient had fatigue as his sole complaint. Seven of the survivors had only x-ray evidence (survey). Some of these developed significant symptoms by the time they were presented for surgery. Only 18 of the 55 patients had objective signs in the chest. Findings included diminished breath sounds, wheeze, bronchial breathing, and dullness to percussion.

Preoperative histologic verification of the diagnosis was possible in only 24 cases. Bronchoscopic biopsy was obtained in thirteen of 48 procedures (27 per cent; Table V). Cytology revealed malignant cells in 15 of 27 cases (56 per cent; Table VI). Positive findings in either or both of these tests were not a common denominator in patients successfully treated.

TABLE V. FIFTY-FIVE FIVE-YEAR SURVIVORS
BRONCHOSCOPIC VERIFICATION

Total procedure	48*	
Biopsy positive	13	(27%)
Tumor seen only	6	(12%)
Negative	29	(60%)

*No bronchoscopic notation in 7 cases.

TABLE VI. FIFTY-FIVE FIVE-YEAR SURVIVORS (1946-1951)
VERIFICATION THROUGH CYTOLOGY

Cases examined	2	
Positive for tumor	15	(56%)
Atypical	8	(30%)
Negative	4	(14%)

There was nothing unusual about the pattern of tumor sites in this group. Right lungs were involved in 31 cases and left lungs in 24. Upper lobes were the site in 30 cases; lower and middle lobes in 19. Six tumors involved main-stem bronchi. Twenty-four were located centrally in the bronchial tree and twenty-eight were peripheral to main lobar bronchi. It was impossible to determine the exact point of origin in 3 cases.

More than one third of the five-year survivors were treated after the tumor had extended to mediastinal lymph nodes, chest wall, or pulmonary vein (Table VII). Therefore, the finding of spread beyond the confines of the lung was not a common factor limiting survival.*

TABLE VII. PRIMARY PULMONARY CARCINOMA
JUNE, 1932

EXTENT OF TUMOR RESECTED	FIVE-YEAR SURVIVORS (55)	ALL OTHERS (206)
Localized to lung	35 (64%)	67 (33%)
Mediastinal lymph node involvement	16 (29%)	50 (24%)
Gross extension	4 (7%)	89 (43%)

TABLE VIII. PRIMARY PULMONARY CARCINOMA
JUNE, 1932—MAY, 1951

EXTENT	CASES	FIVE-YEAR SURVIVORS
Localized to lung	102	35 (34%)
Mediastinal lymph node involvement	66	16 (24%)
Gross extension	93	4 (4%)
Total	261	55

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*During the nineteen-year period under consideration, 34 per cent of resections for localized tumor resulted in five-year survival. Twenty-four per cent of cases with regional lymph node involvement and 4 per cent of cases with gross extension survived five years (Table VIII).

Patients who survived more than five years following resection had no common denominator in histologic pattern The spectrum of cancer type in the survivor group was similar to that in all other cases diagnosed concurrently (Table IX) Thirty eight of the cancers excised are recorded as epidermoid, and thirteen of these are listed as grade 3—the most malignant of epidermoid type Adenocarcinomas totaled nine, two were well differentiated, three were of simplex type (poorly differentiated adenocarcinoma), and four were bronchiolar adenocarcinomas The remaining eight cancers were undifferentiated, five were of a large cell type and three had some foci of epidermoid and simplex tumor

TABLE IX PRIMARY PULMONARY CARCINOMA
JUNE, 1932—MAY, 1951

HISTOLOGY	FIVE YEAR SURVIVORS (55)	ALL OTHERS CLASSIFIED (486)
Epidermoid	38 (69%	290 (60%)
Adenocarcinoma	9 (16%)	130 (27%)
Undifferentiated	8 (15%)	66 (13%)

COMMON DENOMINATORS

Chest x ray abnormality stood out clearly as the first common denominator among the five year cases Every patient had an abnormal shadow on the chest film The shadows appeared as rounded areas, segmental opacifications, and irregular densities—some with central radiolucency (Table X)

TABLE X FIFTY FIVE FIVE YEAR SURVIVORS
X RAY APPEARANCE

Rounded areas	33*
Density with central radiolucence	4
Irregular infiltrate	11†
Segmental or lobar opacity	7

*Six with added segmental or lobar opacity
†One with emphysema one with segmental opacity

Although disturbed lung structures were demonstrated by x ray, the diagnosis remained in doubt This doubt, in many cases, contributed materially to the delay in treatment

The average delay from initial manifestation to diagnosis was 6 7 months in cases who survived five years In all others seen during the same period, the delay was 11 2 months (Table XI) Of the 7 cases discovered by survey chest x ray, 3 had more than four months' delay prior to treatment (Table XII)

TABLE XI PRIMARY PULMONARY CARCINOMA (JUNE, 1932—MAY, 1951)
AVERAGE DELAY

	INITIAL MANIFESTATION TO DIAGNOSIS (MONTHS)
Five year survivors	6 7
All others	11 2
All other resections	11 5

TABLE XII. SEVEN SURVEY-DISCOVERED FIVE-YEAR SURVIVORS
DELAY TO TREATMENT

Less than 3 months	4
Five months	1
More than one year	2*

*Both were localized bronchiolar adenocarcinomas.

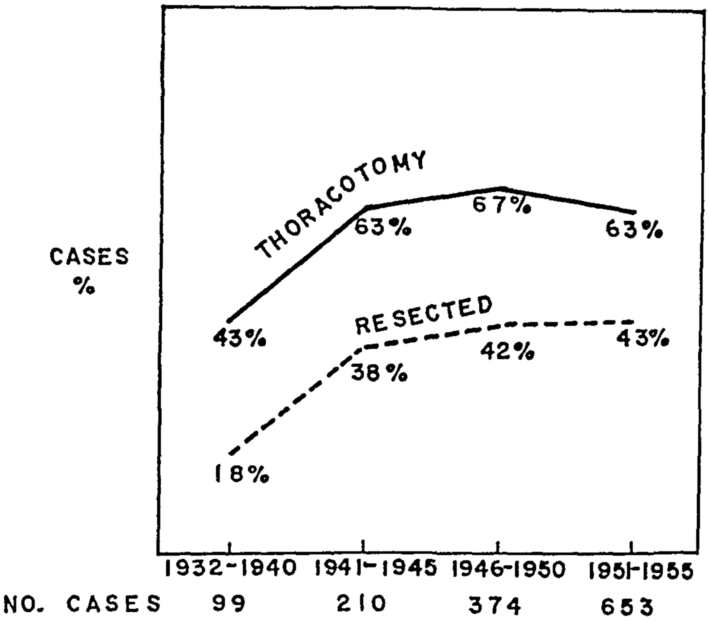

Fig. 2.

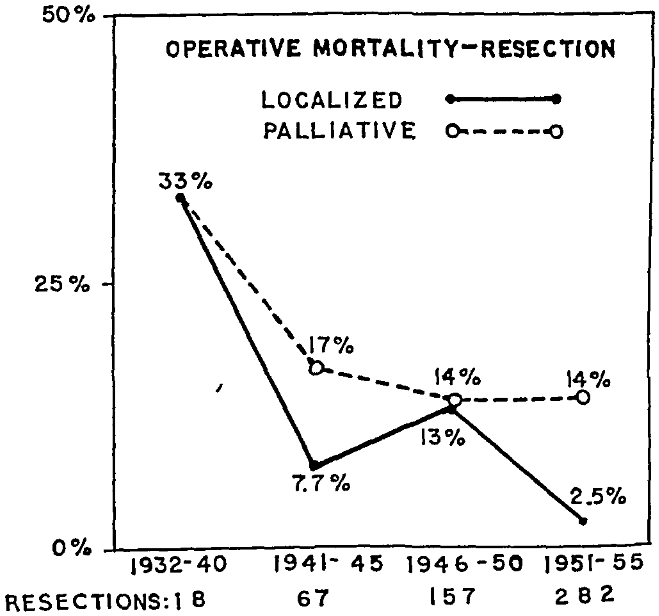

Fig. 3.

The second common denominator was that exploratory thoracotomy was ployed to determine the true nature and extent of the shadow-producing ion. In over one half of the cases, thoracotomy was the only method which ovided material for histologic diagnosis.

The third, and last, common denominator was the application of surgical excision. Among cases treated by x-ray or chemotherapy, alone or in combination, there were no five-year survivors. Pneumonectomy with mediastinal lymph node resection was performed in 51 cases. In one patient wi epidermoid cancer, a block resection of chest wall (three-rib segment was combined with a left upper lobectomy. One with carcinoma simplex h

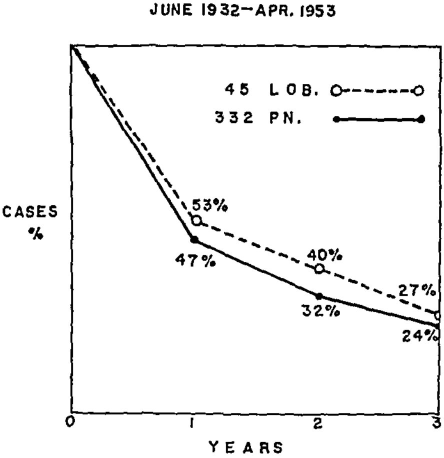

Fig. 4.

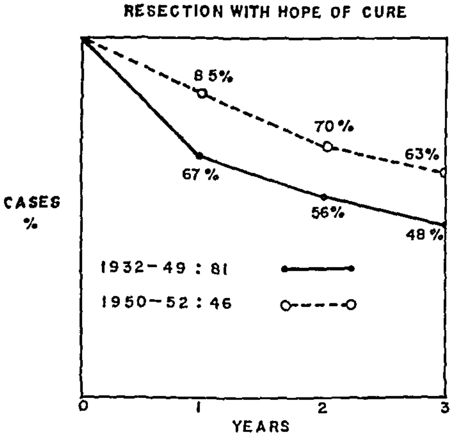

Fig 5.

a two-rib segment of the chest wall resected with the right upper lobe. In one, a left lower lobectomy was performed for bronchiolar adenocarcinoma. The fourth case, who was treated by less than total pneumonectomy, had a strictly circumscribed mass in the left upper lobe with all nodes *negative*. *A total* biopsy was obtained by apicoposterior segmentectomy. On frozen section, only inflammatory reaction was found. Subsequent pathologic examination revealed a small, localized, undifferentiated large-cell carcinoma in the wall of an abscess. Re-operation for a more liberal resection was advised but was refused.

MANAGEMENT

No common factors for survival appear in study of tumor and host characteristics. On the other hand, all common denominators pertain to case management. A simplified and more direct approach to individual problems has become possible as evidence has accumulated to indicate that x-ray, exploration, and resection are the only universal requirements for proper diagnosis and successful therapy of lung cancer.

Fig. 6.—Mrs. S. M. R., 53 years of age. In the patient with an abnormal, isolated, peripheral x-ray shadow, management should proceed directly from x-ray evidence to exploratory thoracotomy. Bronchoscopy can be done immediately prior to insertion of the endotracheal tube for induction of anesthesia. This asymptomatic patient had pneumonectomy in December, 1949, following thoracotomy, biopsy, and a diagnosis of adenocarcinoma. Now, over six years later, she is well and active.

An abnormal x-ray shadow is often the only evidence of the potential existence of cancer. The persistence of the discovery shadow should be verified by adequate, prompt radiologic study. Extended serial x-ray studies unnecessarily add to delay and the dangers of tumor spread. Furthermore, negative bronchoscopy and cytology do not rule out the presence of cancer. The decision to explore should be made on the basis of an abnormal x-ray shadow alone. If peripheral metastases, precarious general condition, or associated disease do not contraindicate, exploration should be undertaken In our clinic, bronchoscopy is performed immediately prior to the insertion of the intratracheal tube which is employed to administer the anesthetic for exploration.

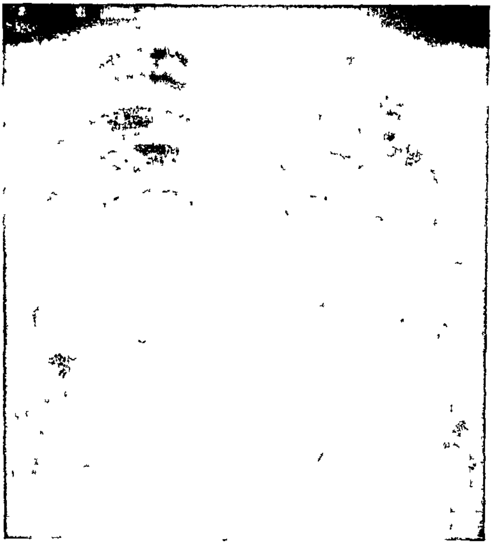

Fig 7—Mr A. A, 42 years of age In the patient with a large, abnormal x-ray shadow separated from the mediastinum by a clear area the decision for exploratory thoracotomy can be made on the basis of the x-ray evidence Bronchoscopy serves to determine the extent of intraluminal bronchial involvement and can be done immediately preceding anesthesia induction This patient had a pneumonectomy in February, 1945, for epidermoid carcinoma, grade 2 He is alive and well now over ten years later

The principal function of bronchoscopy in pulmonary cancer is to determine the integrity of the bronchial system to the sound lung. Occasional patients, who have clinical or x-ray evidence of mediastinal involvement, require bronchoscopic examination prior to decision for thoracotomy.

Exploratory thoracotomy gives access for histologic verification and for determination of tumor extent. All lymph nodes are resected with the dissection originating at the upper and lower limits of the mediastinum. If the lymph nodes are negative, a total biopsy is obtained by subsegmental, segmental, or lobar resection.

Safer resection is the result, to a significant degree, of earlier exploration. Through the years, as the exploration and resection rates have risen (Fig. 2), the mortality and morbidity have declined (Fig. 3). Most thoracic surgeons have elected to employ radical pneumonectomy with or without extensive mediastinal lymph node dissection. However, in recent years, there has been increasing interest in lobectomy for selected cases. In our clinic, as the years have advanced, we have extended the completeness of lymph structure removal and have been more conservative of ipsilateral pulmonary lobes. There has been general agreement for limiting the resection to a lobe in the patient with low pulmonary reserve. Salvage studies suggest that other situations may call for limited resection. Lobectomy, if technically possible, may provide better palliation than pneumonectomy when tumor must be left behind in vertebra, great vessels, heart, or contralateral mediastinum. In limited peripheral and "coin" type lesions with negative lymph nodes, a lobectomy will be just as all inclusive of the primary site as total pneumonectomy. Finally, in localized bronchiolar types, which include papillary adenocarcinoma and alveolar-cell tumors, lobectomy is clearly indicated because of their multicentric tendency. The site of subsequent origins cannot be predetermined. The next lesion may develop in the contralateral lung.

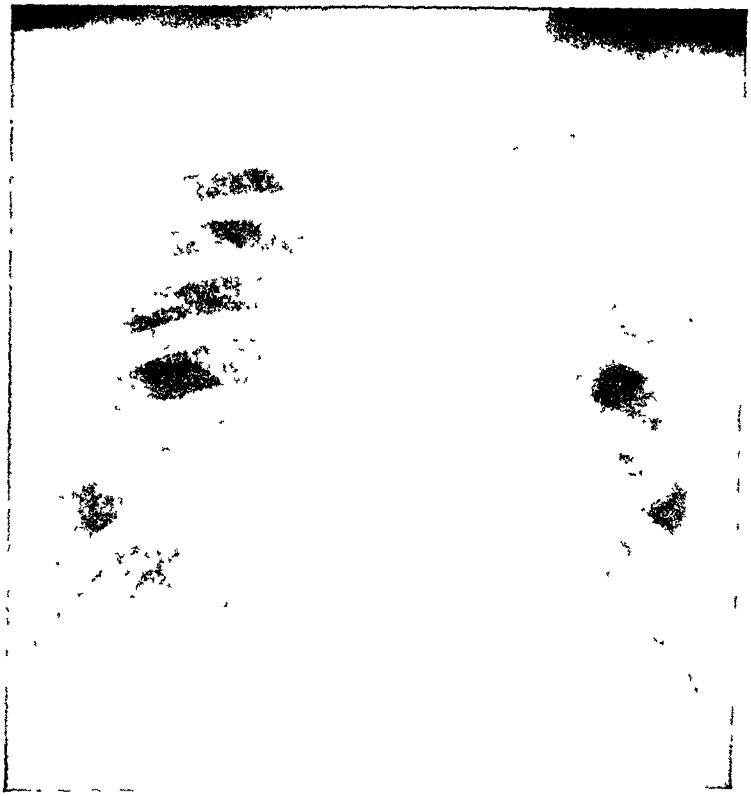

Fig. 8.—Mr. M. L., 50 years of age. When the abnormal x-ray shadow is in close proximity to the hilar region, bronchoscopy is necessary for evaluation of the bronchus to the sound lung. Since the feasibility of resection depends on the bronchoscopic findings, the decision for thoracotomy should await the results of bronchoscopy. In addition, supraclavicular lymph node biopsy can be of assistance. This patient's bronchoscopy permitted only visual examination of a tumor in the left upper lobe bronchus. On Oct. 16, 1948, a pneumonectomy was performed to excise an epidermoid carcinoma, grade 1, with metastases to two of twenty-seven lymph nodes. The patient is alive and well seven years later.

Three-year survival in 45 patients who underwent lobectomy between 1932 and 1953 has paralleled three-year survival of pneumonectomy patients treated during the same period (Fig. 4). Since three-year survival following resection for lung cancer is almost as helpful prognostically as the five-year follow-up, the shorter period may be used as an effective indicator of therapeutic efficiency.

Comparison of three-year salvage of patients with localized lung cancer excised since January, 1950, with three-year salvage prior to that time, in the same type of case, gives substance to the feeling that definite progress is being made in surgical treatment (Fig. 5).

SUMMARY

No common factors for survival appear in the study of tumor and host characteristics. The few common denominators pertain to case management. There are but three:

1. All had chest films which revealed abnormal areas of density.
2. All required surgical exploration to determine the true nature of the shadow-producing lesion.
3. All were treated by excision of the cancer-bearing lung. Significant progress has been made in the prolongation of life for lung cancer victims. While we wait for the discovery of the cause and methods of prevention, further improvement in the salvage of victims is important. The focus of the management program should be on three ingredients essential for success: discovery (x-ray), verification (exploration), therapy (excision).

DISCUSSION

DR. W. EMORY BURNETT, Philadelphia, Pa.—I want to thank the essayists for bringing us up to date on this still very important subject, and to add a few comments which corroborate to some degree what they have to say. Although at first, at the Temple University Hospital, we did lobectomy for cancer of the lung only as a compromise with risk, we were impressed by the marked conservation of function that occurred in these patients, and also by the apparent salvage. This lower mortality gave a great many more people a chance to survive a longer period. This was further bolstered by comments that have already been referred to, side remarks concerning lobectomy as a guilt-producing sort of procedure and, of course, the paper by Dr. Churchill which discussed radical lobectomy gave further support to the idea. Consequently, we have recently applied the rules of application which were outlined by Drs. Robinson and Jones, and found to our surprise that, in the more recent group of 362 cancer patients seen by us between 1948 and 1954, we had done 24 per cent of our resections as lobectomies with mediastinal dissection. Naturally, that is easier to do and more thoroughly accomplished from the right side than the left, but even the left side was dissected as far as possible. Of the five-year survivors of resection done in 1948, it was interesting that, out of 10 such patients, 3 of them had lobectomies; a small group but still of interest. In the earlier group, from 1936 to 1947, when we had considered and screened 429 patients for operability, pneumonectomy was done almost exclusively but there still was an occasional lobectomy. The five-year cures in that group were 4.2 per cent of the entire group considered but 32 per cent of the operated survivors; 24 per cent of these have lived more than five years, from six to fourteen years. It appears, then, from our data, that a tremendous majority of recurrences appear in the first two years postoperatively, and that those who pass that mark have about 70 per cent chance of reaching the five-year period. Second, that the patients without lymph node involvement have twice as good a chance to reach the five-year survival as do those with node involvement. But it was interesting that about one third of our five-year survivors did have lymph node involvement.

DR. CLAIR E. BASINGER, Grand Rapids, Mich.—Dr. Meade, Dr. Rasmussen, and I have recently reviewed our cases from 1948 to 1956. In 310 such cases studied, 54 pneumonectomies were performed and 6, or 11 per cent, of these individuals are still living at the end of three years. In comparison with lobectomies, 31 were performed and 6 of these individuals, or 20 per cent, are living three years or more afterward. Sixty-five of these resections, including both pneumonectomies and lobectomies, have had careful pathologic study. There were 38 of these with glands involved, of whom only 7 individuals, or 11 per cent, are still living. There were 27 without glandular involvement and there are still 20, or 31 per cent, of these individuals alive, 7 of them longer than three years.

I think this is a very timely review of an important surgical problem and a fine selection of papers.

DR. JOSEPH A. WEINBERG, Long Beach, Calif.—We have heard two very fine papers. I would like particularly to direct my remarks to the paper of Drs. Robinson and Jones. They have indicated that there is a great deal of confusion on the subject of indications for lobectomy in the treatment of cancer of the lung. In Taylor and Nathanson's excellent book on lymph node metastases, Dr. Churchill is quoted as saying that the surgical treatment of carcinoma of the lung today is comparable to the treatment of carcinoma of the breast by simple mastectomy without consideration for lymphatic spread. What we know essentially about the surgical treatment of carcinoma in general is that it calls for the thorough removal of the local lesion, together with the accessible regional lymphatics. This principle of surgical treatment applies to carcinoma of the lung just as much as it does to carcinoma in other locations—carcinoma of the bowel and carcinoma of the breast, for example.

It is true that there is much to be desired in the way of earlier diagnosis, but the possibilities of surgery have by no means been exhausted. As long as the treatment remains surgical, our hopes for improvement lie in the direction of improving the lymphatic dissection. We need not be greatly disturbed by the frequently mentioned fact that there are lymphatic cross-communications between the hemithoraces, a fact that is frequently cited by those who take a defeatist attitude on the value of lymph node resection. Actually, it is not rare to find at autopsies on patients dying of bronchiogenic carcinoma that the lesion has remained confined to the hemithorax in which it originated.

It is only by practicing thorough excision of the regional lymph nodes, together with pulmonary resection, that we can give the surgical treatment of pulmonary carcinoma the status of a cancer operation. Since the lymphatic dissection must necessarily be limited with lobectomy, this lesser procedure should be reserved for patients who are poorly suited for pneumonectomy because of the handicap of poor respiratory function.

DR. IRVING A. SAROT, New York, N. Y.—(This discussion was not returned. —EDITOR.)

DR. JAMES E. DAILEY, Houston, Texas.—I must confess that I too was guilty of doing lobectomies for carcinoma of the lung prior to 1950. Unfortunately, Dr. Robinson did not have the time to tell us his indications for these lobectomies so I would like to cite what I consider four indications or justifiable reasons for doing a lobectomy for carcinoma. *First,* in patients with a low pulmonary reserve, such as older individuals with considerable emphysema; *second,* in the patient with a small, isolated and peripherally located tumor nodule; a *third* indication would be a small, localized, bronchial carcinoma with local and hilar nodes apparently not involved with tumor; and *fourth,* the case where the thoracotomy has revealed extensive disease, grossly involved mediastinal nodes, or other structures and it is perfectly obvious that any resection would only result in palliation. This patient will surely die from distant metastases anyway, so there is no sense in sacrificing additional healthy lung. A local resection here may stave off or prevent a horrible excitus with vena caval obstruction, or at least it will abolish the distressing symptoms of cough and hemoptysis. With respect to node involvement, a frozen section biopsy will often be helpful in differentiating inflammatory swelling from carcinoma Furthermore, I feel that in most cases it is technically just as feasible to remove practically all the local hilar and mediastinal glands with lobectomy as it is with pneumonectomy

(slide) In a survey of 111 patients with carcinoma operated upon between 1946 and including 1950, you see that 75 of these were resectable and 36 were nonresectable Of those resected, 16 are still alive and well six to ten years after operation

(slide) In the group of resections there were 16 lobectomies Four of these, or 25 per cent, are still living and well

(slide) I have illustrations of two cases of these lobectomies This first one obviously cannot be classified as an isolated tumor or "coin lesion" The lower and middle lobes were removed in May, 1949, and he is completely well to date

(slide) This second individual was in his late 60's and had what some might call a "coin lesion"—perhaps a "Texas dime"

(slide) A right lower lobectomy was performed on him in March, 1950, and he too shows no signs of cancer today, more than six years later

So one should not really be too pessimistic with respect to attempting partial resections for cancer even though it might seem that the disease is quite far advanced

DR GABRIEL P SELEY, New York, N Y—I also have been practicing lobectomy for carcinoma of the lung in selected cases However, as a result of this experience I now feel very strongly that radical pneumonectomy is the operation of choice for carcinoma of the lung Lobectomy should be practiced only if the patient cannot stand a pneumonectomy due to severe pulmonary insufficiency Proper removal of the mediastinal lymphatics and nodes can be performed only with a pneumonectomy By careful study of the surgical specimen it has been found that nodes close to the lobar hilus are often involved, and yet the mediastinal nodes, mediastinal contents, and paratracheal nodes have not as yet been invaded This indicates that a curative procedure can be done by pneumonectomy when a lobectomy would only be palliative

Nodes that appear normal can contain microscopic tumor cells Morbidity and mortality figures should not be higher but, in fact, lower with pneumonectomy Last even a small lesion when situated near a fissure requires pneumonectomy or at least bilobectomy for proper local removal I think it would be wrong to revert to lobectomy for carcinoma of the lung unless pneumonectomy is absolutely contraindicated

DR PAUL A KIRSCHNER, New York, N Y—I would like to continue the discussion on the value of lobectomy in carcinoma of the lung We too have felt that it has a prime place in the treatment of lung cancer, and at the Bronx Veterans Hospital our resident, Dr Hamilton, has uncovered the following pertinent information In an eight year period, through January 1, 1954, we have performed a total of 113 resections, 24 lobectomies and 89 pneumonectomies There has been no operative mortality in the lobectomy group, as compared to 16 9 per cent in the pneumonectomy group One third of the lobectomy patients have survived at least two years, as compared with one quarter of the pneumonectomy patients Of particular interest is that in a study of autopsy material on patients who have undergone resection, 7 in the lobectomy and 20 in the pneumonectomy group who have died at least three months following operation, the degree of local recurrence, which is a key factor in evaluating any cancer operation, was about the same, roughly 50 per cent Conversely, 40 per cent of each autopsy group (although the lobectomy group is quite small) showed distant metastases without local recurrence

We feel that lobectomy, properly applied, is as radical as pneumonectomy, and this, combined with its inherent low operative mortality rate and unquestioned better functional results, commends it for continued use in the surgery of cancer of the lung

DR LAWRENCE M SHEFTS, San Antonio, Texas—Our survival rates depend very definitely on our selection of patients to whom we offer surgery This is especially true when results are given only on the ones operated on and not on total cases seen Be that as it may, the main purpose (besides diagnostic) of many of our tests, such as scalene node biopsy, is to help us determine to which cases we will offer surgery. As many of the audience here are doing scalene node biopsy for this purpose, I feel that it is important to determine whether it is correct to refuse surgery to the patients with scalene nodes positive for cancer. We have, with the experience of over 320 scalene node biopsies for a large variety of lesions, been refusing surgery when the nodes were positive for carcinoma of the lung. I know, from talking with many, that this has also been in the main the general practice. I question whether this practice is a correct one in all cases. When we stop and think of the cases shown here, some very probably had mediastinal node involvement and, knowing the mediastinum does not lend itself to block dissection, we may expect that some of the cases in these survival groups had, and may have, remaining mediastinal node involvement. In these cases the scalene nodes may well have been positive for carcinoma. Therefore, possibly in refusing operation to some of these patients (particularly those with small isolated lesions) with positive scalene nodes, we may be acting incorrectly. Actually, in a sense, therefore, it would possibly be better not to use scalene node biopsies as a criterion of whether surgery should or should not be done. The use of a positive scalene node, in the aged or in instances of severe cardiorenal disease, to excuse our not operating is understandable and probably correct, but to use it as a blanket reason for refusing surgery may, though it gives one excellent survival rates, result in missing the few that might have been given prolongation of life. I doubt if anyone here, during exploration of a bronchiogenic carcinoma, decides not to do a resection merely because there is mediastinal node involvement. If it is technically resectable, it is resected. Yet we know from experience that a respectable percentage of such cases may well have positive scalene nodes.

DR. RICHARD H. MEADE, Grand Rapids, Mich.—The question has been asked: ''Could you ask the authors if they ever performed resections if the biopsies were positive?'' I presume he means if you cannot feel the glands in the neck, doing just a routine scalene biopsy.

DR. ROBINSON (Closing).—I want to thank the discussants. I feel that our main urpose in presenting this paper has been accomplished, namely, to make it clear that he members of this Association have accepted as a ''respectable member of the family'' obectomy for the surgical treatment of certain patients with carcinoma of the lung.

DR. OVERHOLT (Closing).—In answer to the single question, I should say that we ave, in a few instances, elected to do a resection in the presence of positive cervical odes. Two thirds of the lymph structures within the mediastinum are accessible at horacotomy. Cervical nodes are also within the surgical field. It is too early to know f it is possible to prolong lives by that method or not.

As to lobectomy versus pneumonectomy, I wish to say that we may clarify and implify the surgical approach, but it is never wise to set hard-and-fast rules. So it is ith the extent of the resection for cancer. It depends on circumstances presented by each case.

I should like to show two slides which indicate our own experience with regard to lobectomy. We have gradually elected to limit the resection in more and more cases. The first slide gives the relative percentage of total resections to lobectomy in the period from 1932 to 1950. Then, only 6 per cent of the resections were limited to the lobe. In the past five years, we have performed lobectomy in one third of all the cases. The next slide shows three-year salvage rates as to the extent of the resection. The over-all salvage by lobectomy was 27 per cent in contrast to 24 per cent for pneumonectomy. The cases selected from the two groups are not comparable since the more extensive lesions required the more radical resection. The fact that a substantial number of cases of cancer of the lung, if properly selected, may be salvaged by a more limited resection, is heartening.

TWO UNUSUAL CONGENITAL ANOMALIES OF THE THORAX (1) SUPERNUMERARY RIBS AND (2) ABNORMAL INTRATHORACIC FASCIAL BAND

REVIEW OF LITERATURE

JOHN K. STEVENSON, M.D., AND K. ALVIN MERENDINO, M.D.
SEATTLE, WASH.

APPROXIMATELY one per cent of persons have some variation from the normal pattern of 12 pairs of thoracic ribs. The majority of these will have extra ribs in either the cervical or lumbar region. These may be single (20 per cent) or paired (80 per cent). In the unilateral minority they are more common on the left side (60 per cent).[1,2] Bifid or forked ribs are not rare and frequent reports appear in the literature. Not infrequently, one will find one side of the thorax with fewer than 12 ribs.[3,4]

Careful search of the literature revealed only two previous case reports of supernumerary thoracic ribs.[5,6] No account was found in which the diaphragm was attached to these ribs. Two case reports were found in which there were abnormal intrathoracic muscle bundles or fascial bands.[7,8]

To the surgeon or anatomist, minor congenital or developmental defects of the human body are common and are usually accepted as normal species variation. Occasionally, one encounters a more unusual variation or anomaly which stimulates more than the usual interest or concern and, in the case of surgery, requires a change in operative approach or surgical correction. Rarely does one encounter a variation from the normal which is completely unsuspected and not previously reported. This report deals with two such instances.

CASE REPORTS

CASE 1.—R. M. N., a 17-year-old schoolgirl of American Indian and Irish extraction, was referred to the Surgical Department of the King County Hospital with a diagnosis of asymptomatic atelectasis of the lower lobe of the right lung. There was a previous history of pulmonary tuberculosis on the right side for which she had been hospitalized for two years beginning at the age of five.

She had been well and asymptomatic until March, 1955, when she collapsed at school and was taken to her private physician for examination. An x-ray of the chest showed a shadow of a solid opacity on the right extending from the seventh rib down in a triangular fashion from the hilus to the lateral edge of the diaphragm. Further diagnostic studies, completed at the King County Hospital, including bronchoscopy, bronchograms, and multiple roentgenograms of various views, failed to establish a firm diagnosis (Figs. 1, 2, and 3).

Three "accessory" ribs on the right at the level of the seventh cervical vertebra, and at the level of the sixth and seventh thoracic vertebrae, were demonstrated and it was felt that they had some bearing on the peculiar shadow in the roentgenograms. It was suspected

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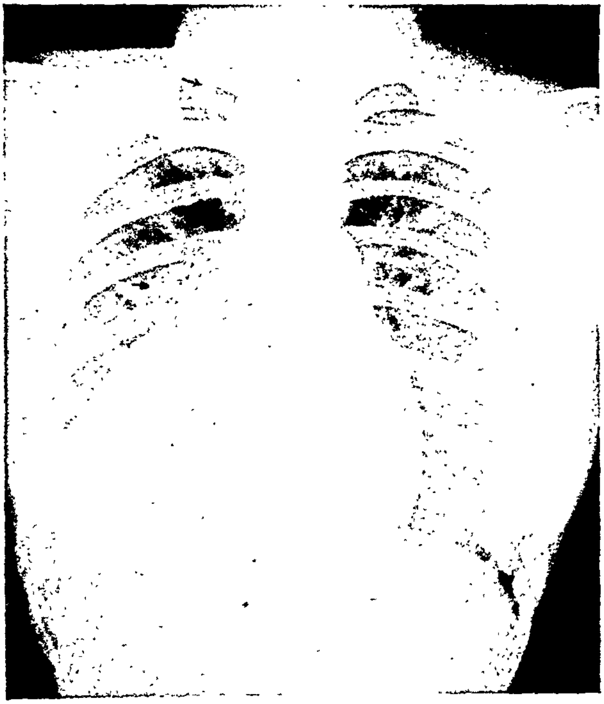

Fig. 1.

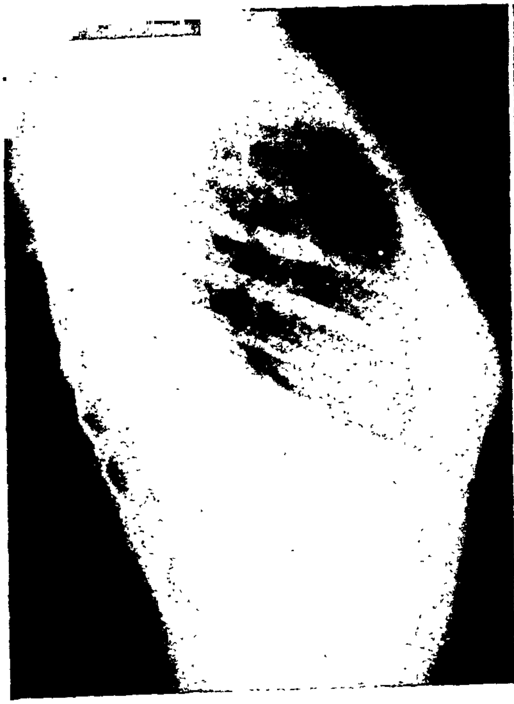

Fig. 2.

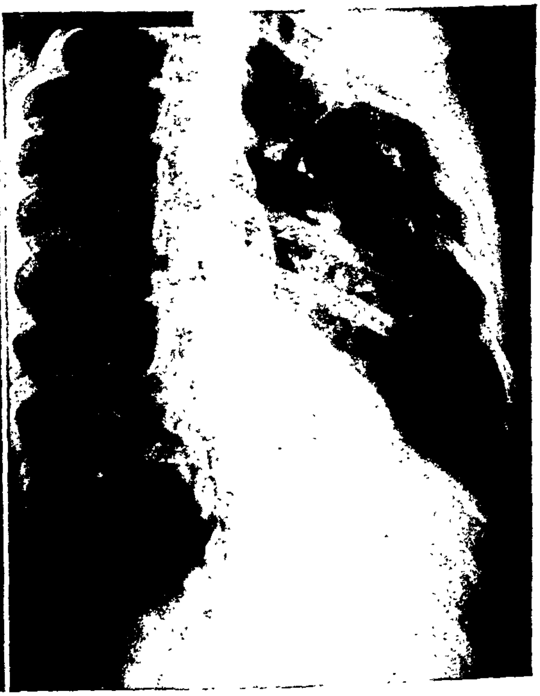

Fig. 3.

Figs. 1 and 2.—Routine posteroanterior and lateral x-ray views of the chest in Case 1 showing the supernumerary ribs C-7, T-6, T-7 on the right with the triangular shadow extending from the level at the sixth thoracic vertebra at the hilus to the base at the lateral thoracic wall.

Fig. 3.—Right anterior oblique x-ray view with higher peak kilovoltage to increase rib detail. The two supernumerary thoracic ribs at the level of the sixth and seventh thoracic vertebrae are seen at the apex of the triangular density.

that this shadow represented an extrapulmonic condition. In April, 1955, the patient was subjected to a right posterolateral exploratory thoracotomy with the following findings:

Ribs: The cervical rib on the right could not be palpated or demonstrated at the time of surgery. The ''accessory'' ribs located at the level of the sixth and seventh thoracic vertebrae extended from their articulation on the vertebral column ventral and slightly caudal to the normal rib articulation. They extended downward and ventrally for a distance of 8 and 11 cm., respectively, and at their termination projected into the thoracic cavity, a distance of 1.5 and 2 cm. beyond the normal wall contour. Their exposed surfaces were covered normally with parietal pleura.

Diaphragm: There was attachment of the diaphragm to the medioventral surfaces of the previously described ''accessory'' ribs at the level of the sixth and seventh thoracic vertebrae at the vertebral column. From this attachment it extended downward and outward in the form of half a cone to a normal peripheral attachment at the base. It was assumed that this abnormal ''tenting'' of the diaphragm accounted for the abnormal x ray findings previously described (Fig. 4).

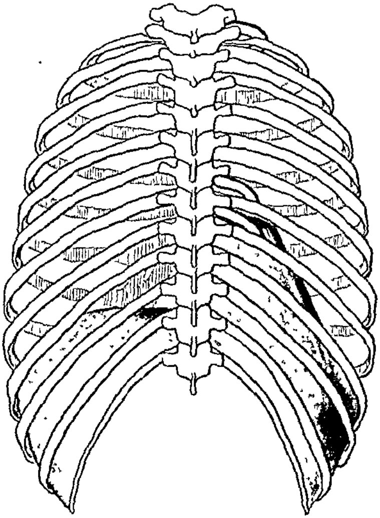

Fig. 4.—Diagrammatic drawing (posterior view) of Case 1, illustrating more clearly the position of the diaphragm and its attachment to the supernumerary ribs on the right. The cervical rib also is indicated.

Lungs.—There was no abnormality found except for indentation at the posteromedial surface of the right lower lobe to accommodate the diaphragmatic "tent."

A small incision in the diaphragm established the relatively normal relationship of the liver below. The phrenic nerve on this side entered the diaphragm adjacent to the pericardial attachment but more dorsal and cephalad due to the elevation, as would be expected. The wound was closed and the patient returned to the hospital ward where she had a completely uneventful postoperative recovery. The patient was discharged to her home on the eighth postoperative day.

Following operation, x-ray films that had been taken in 1944 were now
to us. They demonstrated essentially the same findings as were seen on
x-rays.

Comment.—The combination of the related anomalous development of the ribs and diaphragm might be explained as follows:

At the stage of development of the embryo, when the cephalad and caudad halves of adjacent sclerotomes unite in new combinations to form the primordia of the definitive vertebras, the ventral processes extend laterally into the thoracic wall, giving rise to the primitive ribs. Failure of the component halves of the ventral process of the embryo vertebras to unite as its dorsal process does, would result in two projections extending laterally in that particular space giving rise to two ribs. The dorsal or neural process develops peduncular, transverse, anterior and posterior articular and laminar processes. At this stage, the transverse process lies at a considerable distance from its corresponding rib. The developing ribs meet the outgrowing transverse process, form joints and are invested with their ligaments. Thus, the formation of a twinned rib bud as just described allows two ribs to articulate with one transverse process and vertebral body.[9, 10]

Concurrently, beginning at the level of the highest occipital sclerotome, the septum transversum is undergoing its extensive caudal migration as a result of a faster forward growth of the dorsal body which leaves the ventral structures behind. The common cardinal veins, on their way to the heart, curve around the bilateral pleural canals laterally in the somatic body wall. As these veins shift toward the midline, they carry out a mesentery-like fold, the pleural pericardial membrane, from the pulmonary ridge. Opposite the fourth cervical vertebra, the septum transversum receives the phrenic nerve by way of the pleural pericardial membrane. During this descent the lungs begin to develop in the pulmonary ridge and soon bulge into the bilateral pleural canals. At first there is only a shallow, narrow space between the pulmonary ridge located cranially and a dorsal-lateral extension of the caudal portion of the septum transversum. When the lung can expand caudad or laterally only by invading the adjoining body wall, this small space is enlarged, forming the pleural-peritoneal component of the diaphragm bilaterally by drawing out a shelf of tissue from the caudal portion of the pulmonary ridge. Growth of the lung and shifting of the liver and common cardinal veins create more room between these pleural boundaries. Continued expansion of the pleural cavities progressively increases the area of this membrane, pulling with it a component or extension of the somatic body wall.[11] It is likely that the anomalous attachment of the diaphragm to "accessory" ribs described can be accounted for by failure of release of the descending dorsal portion from the body wall.

When the diaphragm reaches its final location during the second month, the ventral attachment of septum transversum is at the level of the first lumbar segment. With the dorsal medial component (the pleuroperitoneal membrane) and the component of the somatic body wall attached at the level of the sixth and seventh thoracic vertebrae, the peculiar anatomic variation presented here would result.

CASE 2.—G. H., a 39-year-old white man, was referred to the Thoracic Surgical Service of the King County Hospital with the diagnosis of symptomatic mitral stenosis. There was a previous history of rheumatic fever with chorea at 9 to 11 years of age, with the first awareness of a heart murmur a few years later. He was free of symptoms until about five years prior to his referral here when he first became aware of dyspnea and fatigue on exertion. This progressed to the point where he could not work but was able to meet his ordinary daily activities without difficulty.

Diagnostic studies and evaluation indicated that the patient would be clinically and symptomatically benefited by surgical correction of the mitral stenosis He was admitted to the hospital in November, 1954 Mitral commissurotomy was performed through a left lateral incision. As an incidental finding there was a very firm, hard tendinous band approximately 1 5 cm in diameter and 14 cm long, extending from the apex of the thoracic space from its apparent attachment to the undersurface of the second rib anteriorly down to the tendinous central portion of the dome of the left hemidiaphragm This tendinous structure was completely circumscribed by invaginated lung and covered by visceral pleura There was relatively complete fixation of the left hemidiaphragm due to this tendinous attachment The structure

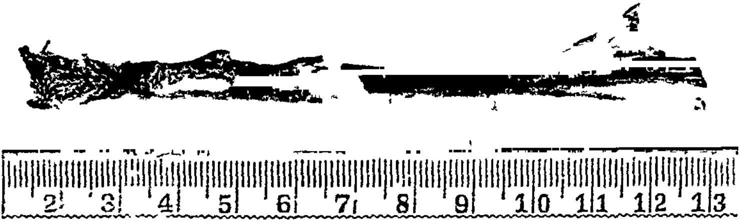

Fig 5—Photograph of the intrathoracic tendinous band which extended from the second rib to the dome of the diaphragm in the patient in Case 2 Histologically the specimen was thought to be tendon

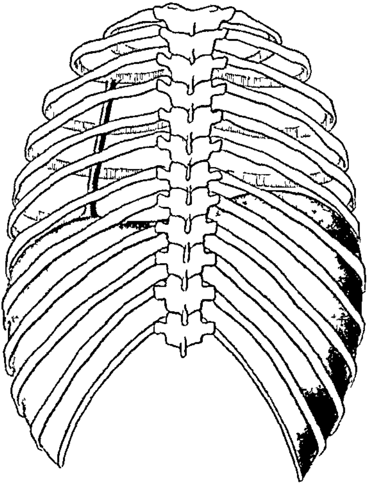

Fig 6—Diagrammatic drawing illustrating the position and attachments of the tendinous band removed from the patient in Case 2 and pictured in Fig 5

was excised, releasing the diaphragm, and the operative wound closed (Figs. 5 and 6). The patient's postoperative course was uneventful and he was discharged to his home on the tenth postoperative day and has since returned to work.

Comment.—Microscopic sections of this fibrinous band showed it to be almost completely acellular with hyalinization of fibers, producing in many areas homogenization so that evaluation of architecture was impossible. However, the over-all structure resembled old hyalinized tendon exhibiting focal areas of calcification. It was impossible to detect whether or not the tendinous structure actually terminated at its apparent attachment to the second rib or extended into the neck to the level of the third or fourth cervical vertebra. Probably, this structure remained as an unresolved remnant of the cranial-dorsal attachment of the septum transversum on the left. It was extended into the configuration found by the process of growth and development described above.

The fact that the fibrous tendinous band described was not demonstrated by chest x-ray would account for its not being discovered earlier.

REVIEW OF LITERATURE

Because of the relatively rare occurrence of such cases and the similarity to the two cases reported here, other cases previously reported will be reviewed (Table I). Although they are not completely similar to the two reported here, their abnormal embryologic development can be explained on the same basis.

TABLE I. REVIEW OF LITERATURE

CASE	SEX	AGE	RACE	SIDE	RIBS	PLEURAL SPACE
Marbut, and DeGinder	F	20	White	Rt.	Supernumerary T-6	Normal
Jacobs	M	43	Negro	Rt.	Supernumerary T-3	Normal
Stevenson, and Merendino	F	17	American Indian	Rt.	Supernumerary C-7, T-6, T-7	Dorsal medial portion of right hemidiaphragm attached to supernumerary thoracic ribs
Allen	M	60	Negro	Rt.	Normal	Two transpleural muscles from sixth thoracic rib to dome of diaphragm
Lutz	F	25	White	Rt.	Incomplete and bifid fourth thoracic rib	Fibrous band from tip of rib to the diaphragm
Stevenson, and Merendino	M	39	White	Lt.	Normal	Tendinous band from anterior surface of second thoracic rib to dome of diaphragm

Marbut and DeGinder (1953)[6] reported the finding of a complete supernumerary, intrathoracic rib in a 20-year-old woman. The rib articulated with the right anterior margins of the sixth and seventh vertebral bodies at the interspace and extended caudally, well within the posterior thoracic wall, and was surrounded by normal lung and visceral and parietal pleura.

Jacobs (1949)[5] reported a supernumerary rib in a 43-year-old Negro. This rib originated from the third dorsal vertebra on its anterolateral surface on the right, articulating independently of the normal rib arising from this vertebra The rib coursed along the posterior thoracic wall downward and slightly lateral on the anterior surface of the normal ribs, external to the pleura It terminated at the level of the eighth thoracic vertebra, 7 cm from the vertebral body There were 12 pairs of thoracic ribs arising in a normal manner

In 1947, Lutz[7] reported the finding in a 25 year old girl of an incomplete bifid fourth thoracic rib on the right side The rib did not articulate with the sternum and was inset medially as compared to the normal thoracic cage Covered with parietal pleura, it projected into the thoracic cage The inferior projection of the fork extended dorsally and caudad to the level of the eighth interspace, approximately 8 cm from the vertebral column A fibrous band extended down from the tip of this lower extension of the rib to the diaphragm

Allen[8] reported, in 1950, a case in which he described finding, in a 60 year old Negro, two transpleural muscles lying in the oblique fissure of the right lung The medial muscle arose from the sixth rib 1 inch from the vertebral column and inserted into the central tendon just behind the caval opening The lateral muscle took origin from the sixth rib 3 inches from the vertebral column and inserted into the extreme lateral aspect of the central tendon

It is likely that this anomalous finding is closely related to that of our first case in that these transpleural muscles arise from the component from the pleuroperitoneal membrane and/or its component from the somatic body wall

SUMMARY AND CONCLUSIONS

1 Two unusual congenital anomalies of the chest are reported

2 An embryologic basis for their occurrence is considered

3 Similar congenital abnormalities previously reported are reviewed

4 Even though the congenital anomalies described were incidental and asymptomatic, they were of clinical significance It should be recognized that these variations do exist and can present difficult diagnostic problems

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PNEUMONECTOMY FOR PULMONARY TUBERCULOSIS

AN ANALYSIS OF 151 CASES

VIKING OLOV BJÖRK, M.D.
STOCKHOLM, SWEDEN

NO attempt has been made in this paper to compare the results obtained in pneumonectomy for pulmonary tuberculosis with those reported in the literature. Materials of pulmonary tuberculosis are often composed of cases with a different degree of severity which influences the results. It is therefore considered of more value to report one group and discuss the pathophysiologic problems arising in the surgical treatment of "bad risk" patients undergoing pneumonectomy for pulmonary tuberculosis.

MATERIAL

Many patients undergoing a pneumonectomy for pulmonary tuberculosis are in a really bad condition. They may be toxic, having had fever, with considerable expectoration, for several months. The respiratory reserve is usually very small due to disease of the only functioning lung or residues after a previous pneumothorax. One patient has had pneumonectomy performed during contralateral pneumothorax treatment.

Of the 151 patients operated upon, 16 are dead and 111 have been followed up for one to five years or more. Twenty-two patients were excluded as the observation time was less than one year. Two patients could not be traced.

Age.—Old age is no contraindication for the removal of a destroyed lung. The oldest patient in this material was a 64-year-old woman. She withstood a right extrapleural pneumonectomy and later a 10-rib thoracoplasty in two stages very well and her sputum and gastric washings one year later were negative to guinea pig tests. The youngest patient was an 11-year-old girl

TABLE I. AGE AND SEX DISTRIBUTION IN 151 PATIENTS UNDERGOING PNEUMONECTOMY FOR PULMONARY TUBERCULOSIS

AGE	MEN	WOMEN	TOTAL
10-19	1	1	2
20-29	8	15	23
30-39	25	34	59
40-49	19	21	40
50-59	13	13	26
60-69	0	1	1
Total	66	85	151

From Sabbatsberg Hospital: Surgeon-in-Chief, C. Crafoord, M.D., Professor—St. Göran Hospital: Physician-in-Chief, A. Westergren, M.D., Professor—Söderby Hospital: Physician-in-Chief, T. Bruce, M.D., Docent.

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who underwent a left pneumonectomy without any space-diminishing procedure. The age and sex distribution are shown in Table I and Fig. 1.

INDICATIONS FOR PNEUMONECTOMY

A. Indications Due to Pathology.—A pneumonectomy is usually performed only when the lung is destroyed by tuberculosis.

1. Stenosis of the main bronchus: In 37 cases, i.e., 25 per cent, there was a stenosis of the main bronchus. This finding in itself is no absolute indication for a pneumonectomy. It is the combination of a destroyed lung with a stenosis of the main bronchus that makes it necessary to remove the whole lung. If some part of the lung parenchyma is without pathologic changes, it may be saved. Then a bronchography has to be done in order to outline the length of the stenosis and to exclude the possibility of bronchiectasis behind the stenosis. In this material, it has been possible in 6 patients to do a resection of the main bronchus and a bronchotracheal or bronchial anastomosis. In 2, it was possible, after division of the 4 upper pairs of intercostal arteries and mobilization of the aorta, to anastomose the left lower lobe bronchus to the trachea. Most patients coming to surgery, however, already have a destroyed lung behind the stenosis.

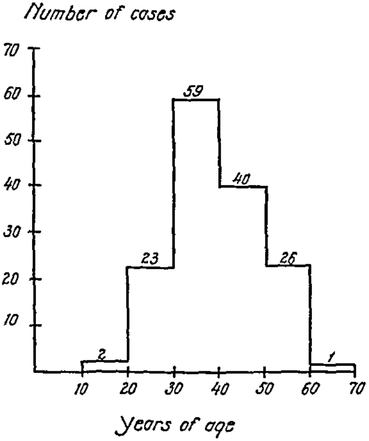

Fig 1.—Age distribution in 151 cases of pneumonectomy for tuberculosis.

A bronchial stenosis may be due to (1) endobronchial tuberculosis or (2) peribronchial tuberculous glands, or both. In most cases, it is difficult at the time of operation to evaluate the importance of each factor. In 5 patients, a number of calcified glands were found constricting and compressing the main bronchus. In the 10 patients, in whom endobronchial tuberculosis was the main cause of the bronchial stenosis, it was often necessary to spend a considerable time separating the main bronchus from the pulmonary arte

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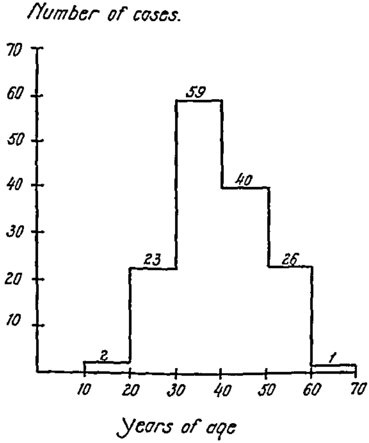

FIG. 1—Age distribution in 151 cases of pneumonectomy for tuberculosis.

A bronchial stenosis may be due to (1) endobronchial tuberculosis or (2) peribronchial tuberculous glands, or both. In most cases, it is difficult at the time of operation to evaluate the importance of each factor. In 5 patients, a number of calcified glands were found constricting and compressing the main bronchus. In the 10 patients, in whom endobronchial tuberculosis was the main cause of the bronchial stenosis, it was often necessary to spend a considerable time separating the main bronchus from the pulmonary artery. In some of these cases, it has been necessary to do this separation with a knife. The bronchus and the pulmonary artery seem to be grown together by a very dense fibrotic tissue and no glands are found in the stenotic area.

The left main bronchus was stenosed more often (31 cases) than the right main bronchus (6 cases—see Fig. 2). This is probably due mainly to the fact that the left main bronchus is much longer (5 cm.) than the right one (2 cm.). This is the only group of cases where there has been a dominating incidence of the left lung. In the other groups, there has been roughly an equal side distribution.

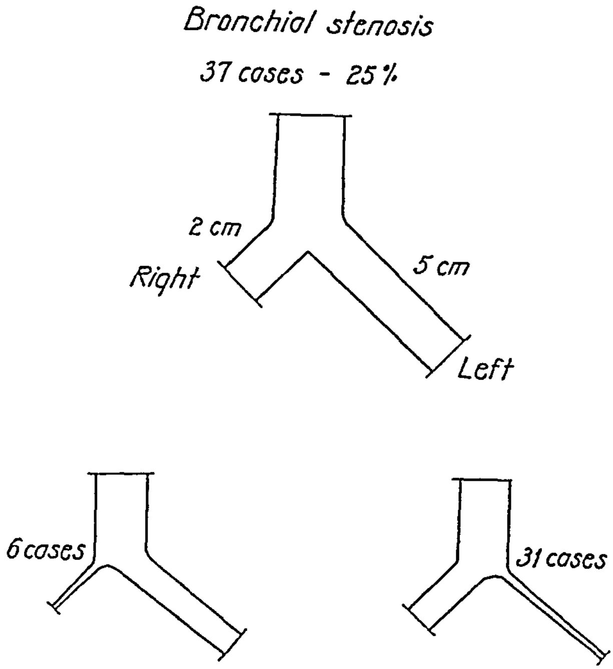

Fig. 2.—There is a dominating incidence of left-sided bronchial stenosis.

2. Tuberculous cavitation (destroyed lung): The most common indication for a pneumonectomy was a destroyed lung with a number of cavities. In 19 of these cases there was a lobar bronchial stenosis as well. Some patients also had cavitation in the remaining lobe after a lobectomy (6 cases), and the combination of pulmonary tuberculosis and empyema (15 cases). In the group with empyema, 9 patients had a bronchopleural fistula before the operation. In several patients with empyema sent for an extrapleural pneumonectomy, it has, however, been possible to save the entire lung or part of it. Of the whole group of 151 cases, 101 or two thirds of the material were extrapleural resections. Most of these patients had a calcified fibrothorax needing considerable effort to free it.

B. Indication Due to Pathophysiology.—In cases where, from the x-ray investigations alone, it was difficult to decide whether a pneumonectomy should be performed or whether some segments should be left, bronchospirometry is the most important function test. The following principle has then been used in my cases: If the bronchospirometry shows an oxygen uptake of 10 per cent or less on the side to be operated on and the operation is not in itself expected to improve the function considerably (by decortication or bronchial anastomosis), a pneumonectomy is performed. Early in this series, a ventilating emphysematous lobe with minimal function but without active tuberculosis was left in some instances (instead of doing a pneumonectomy at once). By leaving this plomb of nonfunctioning lung tissue, a much smaller thoracoplasty had to be done. At follow-up, however, a reactivation has been found in the "lung plomb" in several cases. There is practically no advantage in leaving a functionless lobe. Only a negligible amount of blood passes through its pulmonary artery. Therefore, pulmonary hypertension cannot be prevented by leaving nonfunctioning lung tissue. On the other hand, it is a disadvantage to leave nonfunctioning lung tissue, thereby increasing the dead space and, when such a lobe has been the source of a positive sputum, it has to be removed at a new operation.

If the bronchospirometry shows 20 per cent or more of the oxygen uptake on the side to be operated on, every effort is made to save as much functioning lung tissue as possible at the resection. In cases having between 10 and 20 per cent of the oxygen uptake on the side to be operated on, it is often possible to save some part of the lung (usually the basal segments). The final decision has then to be made during the operation and often after considerable time has been spent on a decortication. In the presence of contralateral disease, as many segments as possible are left behind.

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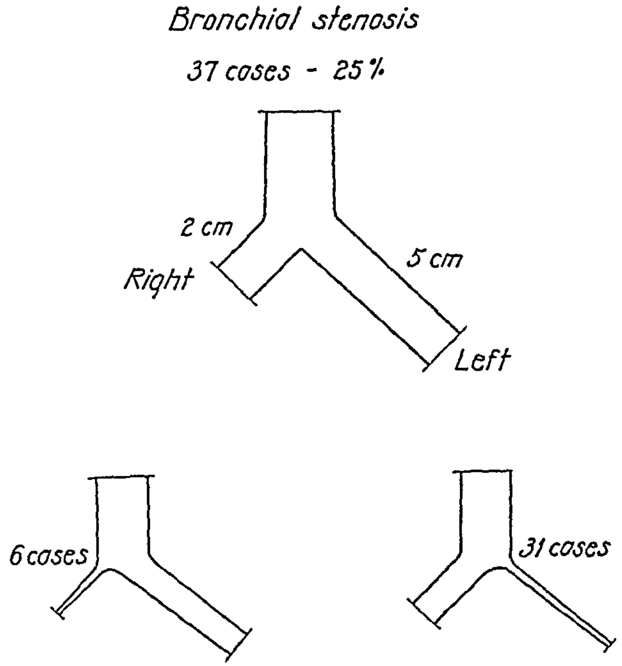

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PREOPERATIVE INVESTIGATION OF LUNG FUNCTION

The most important information regarding the pulmonary function is obtained by a study of all x ray films from the beginning of the disease The maximal movements of each diaphragm are recorded also

A The Maximal Breathing Capacity—The maximal breathing capacity (MBC) was then recorded The lowest preoperative value for MBC was 19 L/min The patient, a 37 year old man, withstood an extrapleural pneumonectomy and later a total thoracoplasty and the sputum and gastric washings were negative to guinea pig tests one year later when the MBC was 18 L/min (see Figs 8*A* and 8*B*) Fifty per cent of the tested male patients had a preoperative value of less than 69 L/min Fifty per cent of the female patients had a preoperative MBC of less than 49 L/min, 6 having an MBC between 20 and 29 L/min

B The Vital Capacity (VC)—The lowest preoperative value of vital capacity for men was 1 1 L with 50 per cent of the patients below 2 6 L The lowest value for women was 1 1 L with 50 per cent of the cases with values for VC below 2 0 L

C The Bronchospirometry—A bronchospirometry was performed only in 49 cases, where it was difficult to decide if some part of the lung could be left Thirty of these patients had an oxygen uptake of less than 10 per cent on the side to be operated on (21 had less than 5 per cent) Thirteen patients had an oxygen uptake of between 10 and 20 per cent and only 6 had more than 20 per cent on the side to be operated on. In several instances, where a very low oxygen uptake was found, but where a significant increase of the oxygen uptake of that lung was found when placed lowermost with the patient in the lateral position, it was possible to save lung tissue after a decortication. Then the thickened pleura was greatly responsible for the impaired function.

D. The Residual Capacity.—The residual capacity was investigated in 81 cases and was below 35 per cent of the total capacity in 63 cases, between 35 and 40 per cent in 8, between 40 and 45 per cent in 7, and above 45 per cent in 3.

E. The Pulmonary Artery Pressure.—The pulmonary artery pressure was investigated in 15 cases before operation and in 12 cases during the operation. Nine patients had a mean pressure at rest or during operation of more than 20 mm. Hg. Of these, 1 patient, with 29 mm. Hg resting pressure, needed tracheostomy and 3 patients with 22, 23.5, and 27 mm. Hg mean pressure needed tracheostomy with prolonged artificial ventilation. Five patients with a mean pulmonary artery pressure of 21, 23, 25, 29, and 37 mm. Hg had an uncomplicated immediate postoperative course. The patient with a pressure of 37 mm. Hg died later on after an infection with bronchial fistula. Two patients with 17 and 19 mm. Hg mean pressure have later died in cor pulmonale. It therefore seems to be difficult to draw any conclusion from the pulmonary artery pressure in regard to the operative risk, at least from this material.

METHOD OF TREATMENT

Only in 1 patient, a girl of 11 years of age, has a space-diminishing procedure been omitted. Otherwise, it has been felt important to obliterate the space for the following two reasons: (1) to diminish the risk of infection with an eventual bronchial fistula, and (2) to keep the mediastinum as close as possible to the midline to prevent overdistention of the remaining lung with emphysema, and lessen the risk of reactivation of tuberculosis.

In this material, there has been a change, from a procedure in several stages where first the thoracoplasty preceded the resection, to one-stage operation with an osteoplastic wall thoracoplasty.

1. In a group of 49 patients, a curative thoracoplasty was first performed in 2, 3, or 4 stages. After a period of from one to ten years, the pneumonectomy was performed after the thoracoplasty was considered a failure.

2. In a group of 47 patients in whom a pneumonectomy was indicated, a first-stage 5-rib (or 3-rib) thoracoplasty with apicolysis was performed. After some months, the pneumonectomy was performed and the rib resection was extended down to include the ninth rib on the left side and the tenth rib on the right side. One 28-year-old man in the group, with a giant cavity in the right upper lobe, had a spread to the left lower lobe after the first-stage thoracoplasty. The pneumonectomy was performed after one year but at follow-up there was a tuberculous cavity surrounded by tuberculosis in the basal segments of the left lower lobe. This method is now abandoned in favor of the one-stage procedure. In some cases where a 5-rib thoracoplasty had been performed as a preliminary operation, the diaphragm was mobilized and resutured at a higher level, i.e., to the fifth intercostal muscle bundle after the pneumonectomy instead of an extended rib resection. It is doubtful if much is to be gained by this procedure as compared to a phrenic crush.

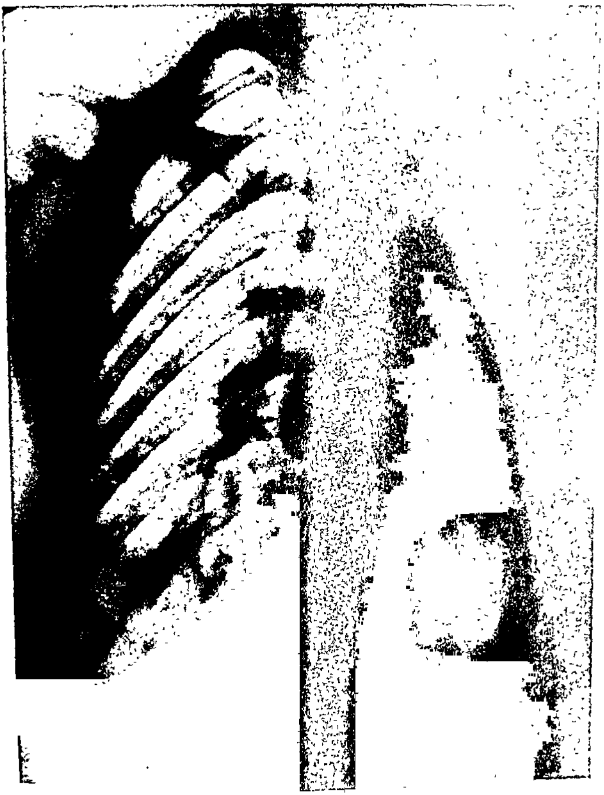


Fig. 3A.—The mediastinum is kept in the midline one year after an osteoplastic wall thoracoplasty.

3. In a group of 17 patients, the pneumonectomy was performed as the first operation and a total thoracoplasty at a later date; in one stage in 12 cases, and in two stages in 5 cases. A total thoracoplasty, sometime after a pneumonectomy, is a very well-tolerated procedure and need usually not be divided into two stages.

4. To achieve a one-stage procedure, a plastic plombe (Polystan) wa introduced intrapleurally in 7 instances and extrape [illegible] after com

pletion of the pneumonectomy. Only patients were chosen in whom there was considered to be no danger of infection. At the follow-up after one year there has been no untoward effect of the plombe.

5. In 4 cases, a total thoracoplasty with rib resection was performed at the same stage as the pneumonectomy. Only patients in a very good condition were chosen.

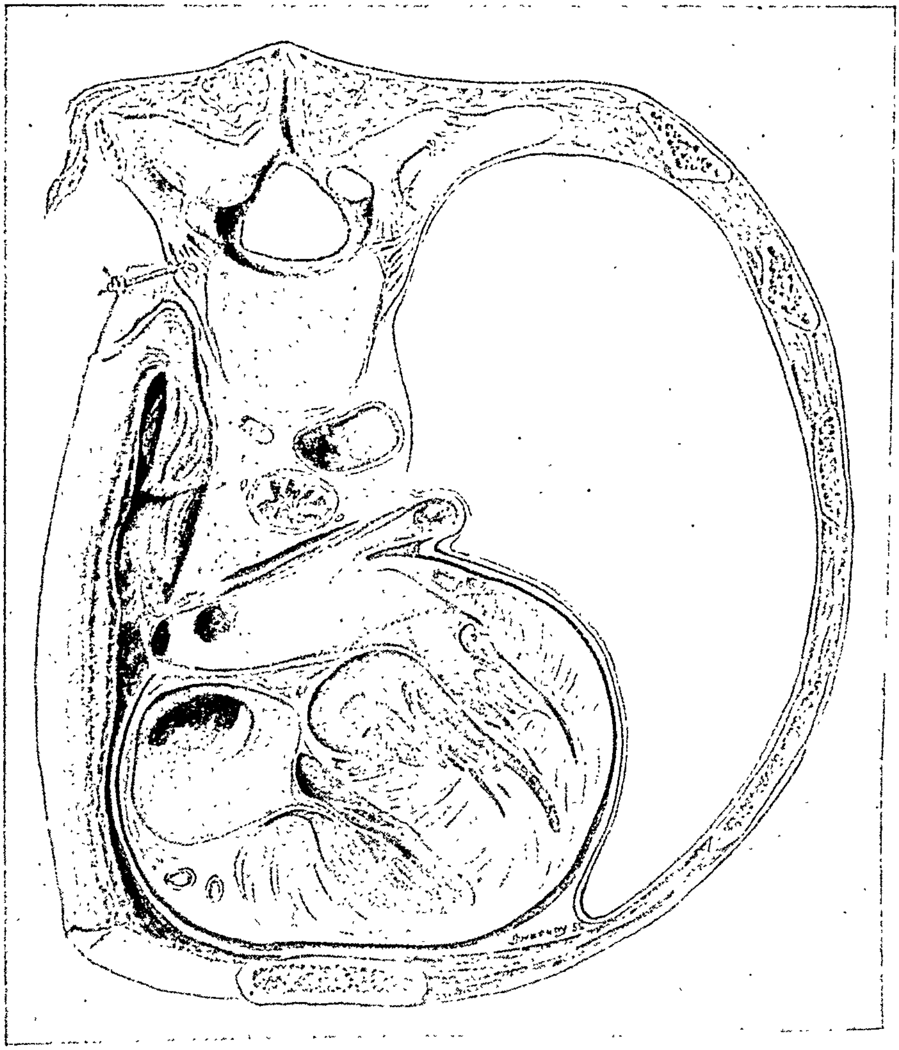


Fig. 3*B*.—The posterior ends of the ribs, bent or fractured in the costal cartilages, are fixed to the vertebral bodies through the costovertebral ligament behind the rib by nylon threads. (From Björk.[4])

6. In order to prevent the paradoxical movement of the mediastinum in the postoperative period and to prevent a later mediastinal shift to the side operated upon, an osteoplastic wall thoracoplasty has been worked out and applied in 21 cases. With this method, we have a one-stage procedure which can be applied to patients with a very limited respiratory function and with tuberculous empyema. In 13 of the patients in this group, an extrapleural pneumonectomy had to be performed. There was only one complication with infection. Five patients in this group needed prolonged artificial ventilation through a tracheostomy during the postoperative period. The method includes most often a resection of the first rib and posterior parts of ribs 2 to 9 on the left side and 2 to 10 on the right side. Then the posterior ends of the ribs, bent or fractured in the costal cartilages, are fixed to the vertebral bodies through the costovertebral ligament by nylon threads through drill holes in the posterior ends of the ribs. Thus, the mediastinum is kept in the midline for the future (see Figs. 3*A* and 3*B*).

From a technical point of view, I recommend a one-stage procedure with an osteoplastic wall thoracoplasty after pneumonectomy for tuberculosis. The bronchus is cut at a level a few millimeters below carina, even on the left side. The bronchus is closed with isolated terminal sutures of chromic catgut on an Atraumatic needle and covered with mediastinal pleura. Some streptomycin crystals are placed under the pleural flap.

RESULTS

Dead.—Of the 151 patients, 16 are dead. In the group of 101 patients with extrapleural resection, 14 were lost (14 per cent); in the group of 50 patients with intrapleural resection, 2 cases or 4 per cent were lost (Figs. 4 and 5).

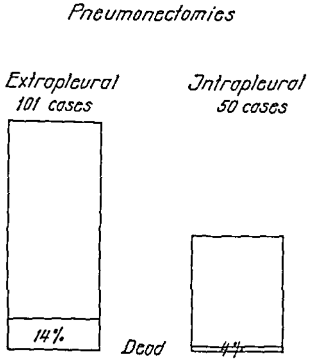


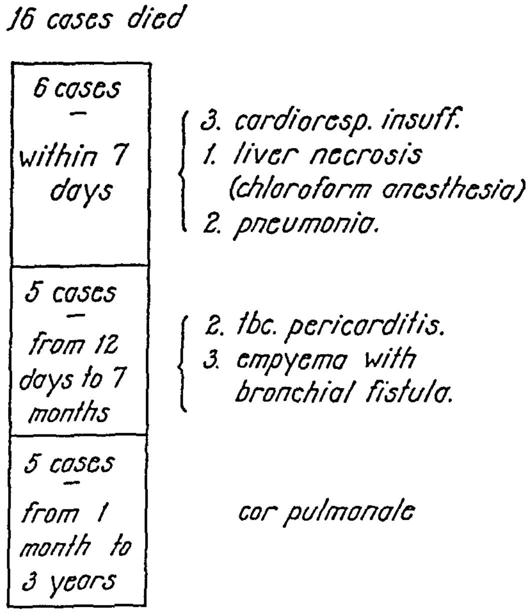
Fig. 4.—Fourteen per cent were dead in the group in which extrapleural pneumonectomies had to be performed. Only 4 per cent died in the group of patients who had had intrapleural pneumonectomy The mortality percentage will reflect the difference in severity of disease in the two groups.

Five patients died within one week of the operation: Two patients never regained consciousness after operation (1 had a massive spillover, the other went into pulmonary edema due to cor pulmonale). One patient died after thirty-two hours with liver necrosis due to chloroform anesthesia. One patient (44 years old) died after thirty-two hours in ventilatory insufficiency (post-mortem examination showed cor pulmonale). One 49-year-old man died with bronchopneumonia of the remaining lung and diffuse bleeding in the space, one week after an extrapleural pneumonectomy with osteoplastic thoracoplasty. No source of the bleeding was detected at the post-mortem examination.

Six patients died from infection between twelve days and seven months after the operation:

Two patients died from tuberculous pericarditis, both on the twelfth day after operation. Therefore a special effort is made during resection for tuberculosis to avoid opening the pericardium.

Three patients died from empyema with a bronchial fistula. A 50-year-old man developed a staphylococcus chest wall infection with empyema and bronchial fistula and died after three weeks. The other 2 patients died after five weeks and seven months with a tuberculous empyema and bronchial fistula. Attempts to close the bronchial fistula after reamputation and adding an extensive resection of the chest wall have been of no help in patients with bronchial fistula due to tuberculous infection.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cor pulmonale

Fig. 5.—Five patients have died from cor pulmonale. This number is expected to increase with time.

One 34-year-old woman died three months after a left-sided pneumonectomy and two days after an upper lobectomy on the right side with a simultaneous osteoplastic thoracoplasty. She vomited and developed an aspiration pneumonia in the right lower lobe. In these patients with an extremely low respiratory reserve, a tracheostomy is now performed at the end of the operation. Then an ordinary tracheostomy cannula, provided with a rubber cuff, is used for artificial ventilation when indicated. This rubber cuff will also prevent aspiration. As there is very little tidal volume, it will otherwise be difficult for the patient to expectorate the aspirated material.

Five patients died from ventilatory insufficiency and cor pulmonale one month to three years after the operation.

Other Complications.—

Three patients had a primary tracheostomy and prolonged artificial ventilation for 3, 10, and 12 days due to ventilatory insufficiency.

Two patients had the same treatment due to postoperative infiltration in the only remaining lung. This infiltration had disappeared after seven to ten days with antimicrobial and respirator treatment.

Four patients developed pulmonary edema, 2 of whom had to have a tracheostomy.

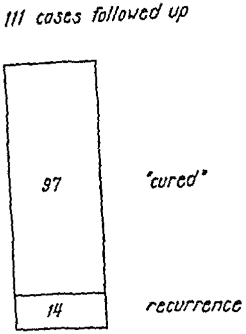

Fig. 6—Ninty-seven patients of 111 were considered "cured"

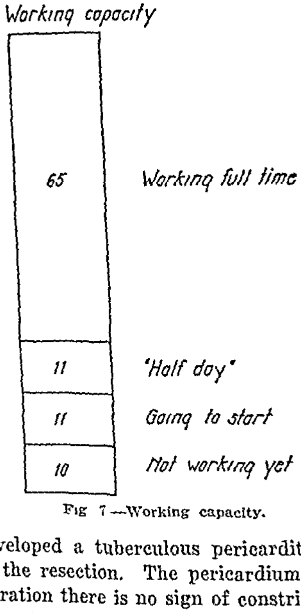

Fig 7—Working capacity.

One patient developed a tuberculous pericarditis after a lesion of the pericardium during the resection. The pericardium was aspirated and now four years after operation there is no sign of constrictive pericarditis.

Three patients needed revision thoracoplasty due to chest wall infection; this operation consisted of a wide excision of the chest wall leaving only skin on the mediastinum.

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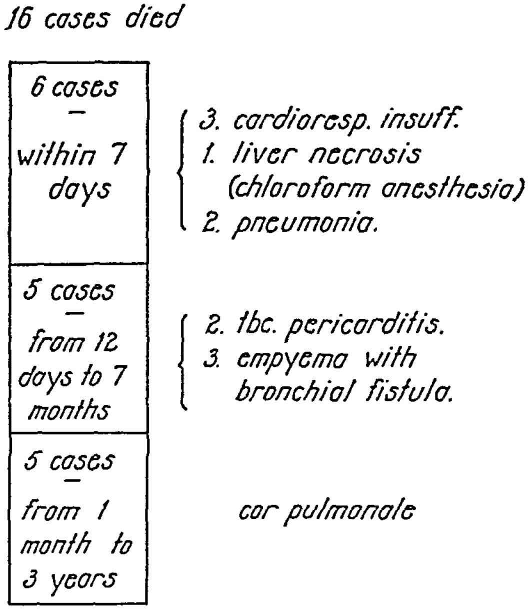
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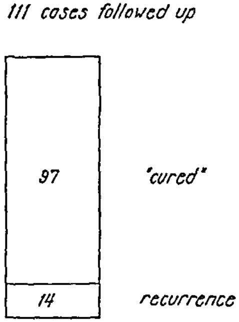

Fig. 6—Ninty-seven patients of 111 were considered "cured"

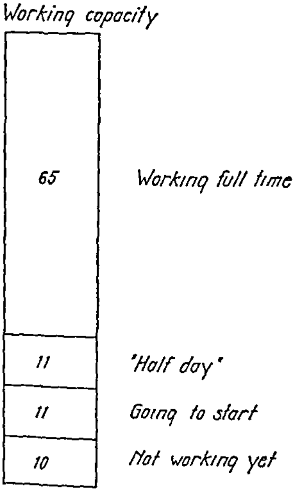

Fig. 7—Working capacity.

One patient developed a tuberculous pericarditis after a lesion of the pericardium during the resection. The pericardium was aspirated and now four years after operation there is no sign of constrictive pericarditis.

Three patients needed revision thoracoplasty due to chest wall infection; this operation consisted of a wide excision of the chest wall leaving only skin on the mediastinum.

Seventeen patients had to have sutures removed from the bronchial stump before chromic catgut was used as suture material for the bronchus; stainless steel sutures have been removed as long as four years after the operation.

"Cured Patients."—

The aim of the surgical treatment for pulmonary tuberculosis is to make the patient free from tubercle bacilli in the sputum. Therefore, a patient is considered as "cured" if at the one-year follow-up the guinea pig test on sputum and gastric washing, as well as the culture and the direct smear of sputum, is negative on three consecutive days and no active disease is found on the x-ray investigation. All these criteria were fulfilled in 91 of the "cured" patients. In the remaining 6 patients, it was not possible to obtain sputum and therefore only the guinea pig test on the gastric washing was performed and found nega-

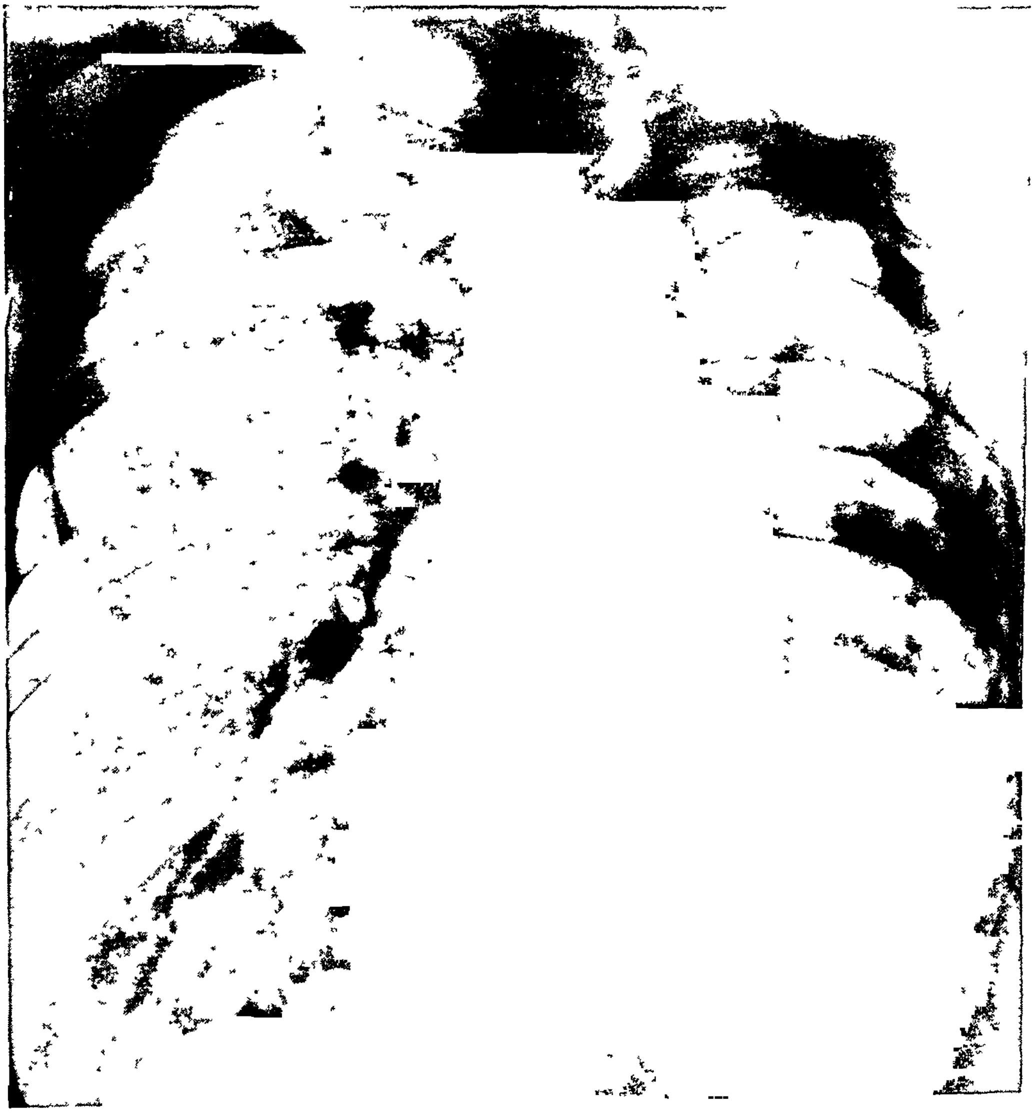

Fig. 8A.—An x-ray taken of a 37-year-old man with a left-sided tuberculous empyema, bronchopleural fistula, and a destroyed lung. Maximal breathing capacity 19 L./min

tive, thus 87 per cent of the 111 patients followed up are considered *to be* "cured." Some patients have been followed for five years but in the majority only the one-year follow-up is reported (Fig. 6).

Working capacity: Of the "cured" patients, 25 men and 39 women (65 per cent) were working full time. Four men and 6 women (11 per cent) were doing a half day's work. Eleven men and 12 women had not yet started work one year after the operation, but, of them, 5 men and 7 women were going to take up work again in the near future. Housework and office work was most often represented, but a nurse, an officer, a driver, and a bricklayer performed full-time work one year after operation (Fig. 7).

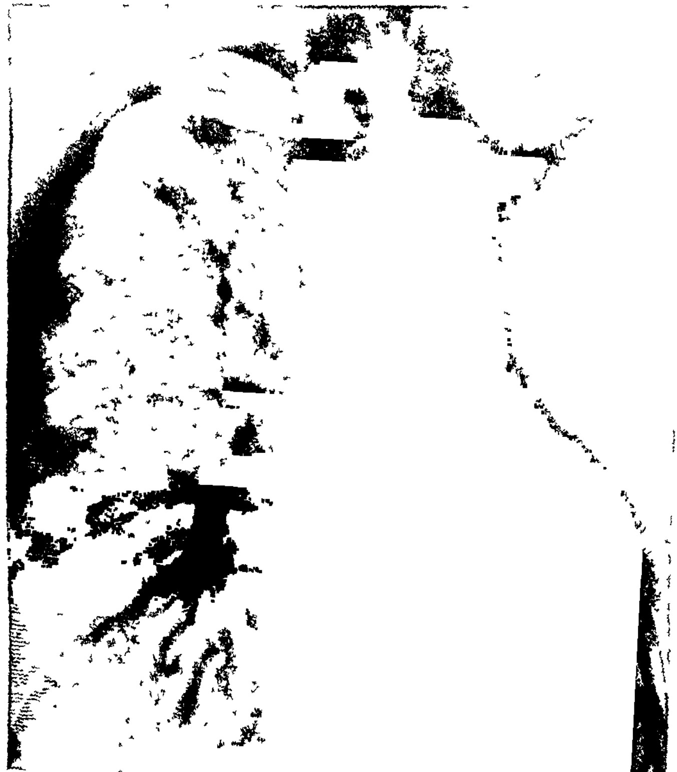

Fig 8B.—An x-ray made one year after operation The maximal breathing capacity is 18 L/min The guinea pig test is negative on sputum and gastric washings

The arm movements: The arm movements were normal in 42 (48 per cent) patients In the remaining patients there was an impaired ability to bring the arm on the operated side straight up in the air (i e., 180 degrees). Twenty-one

Seventeen patients had to have sutures removed from the bronchial stump before chromic catgut was used as suture material for the bronchus; stainless steel sutures have been removed as long as four years after the operation.

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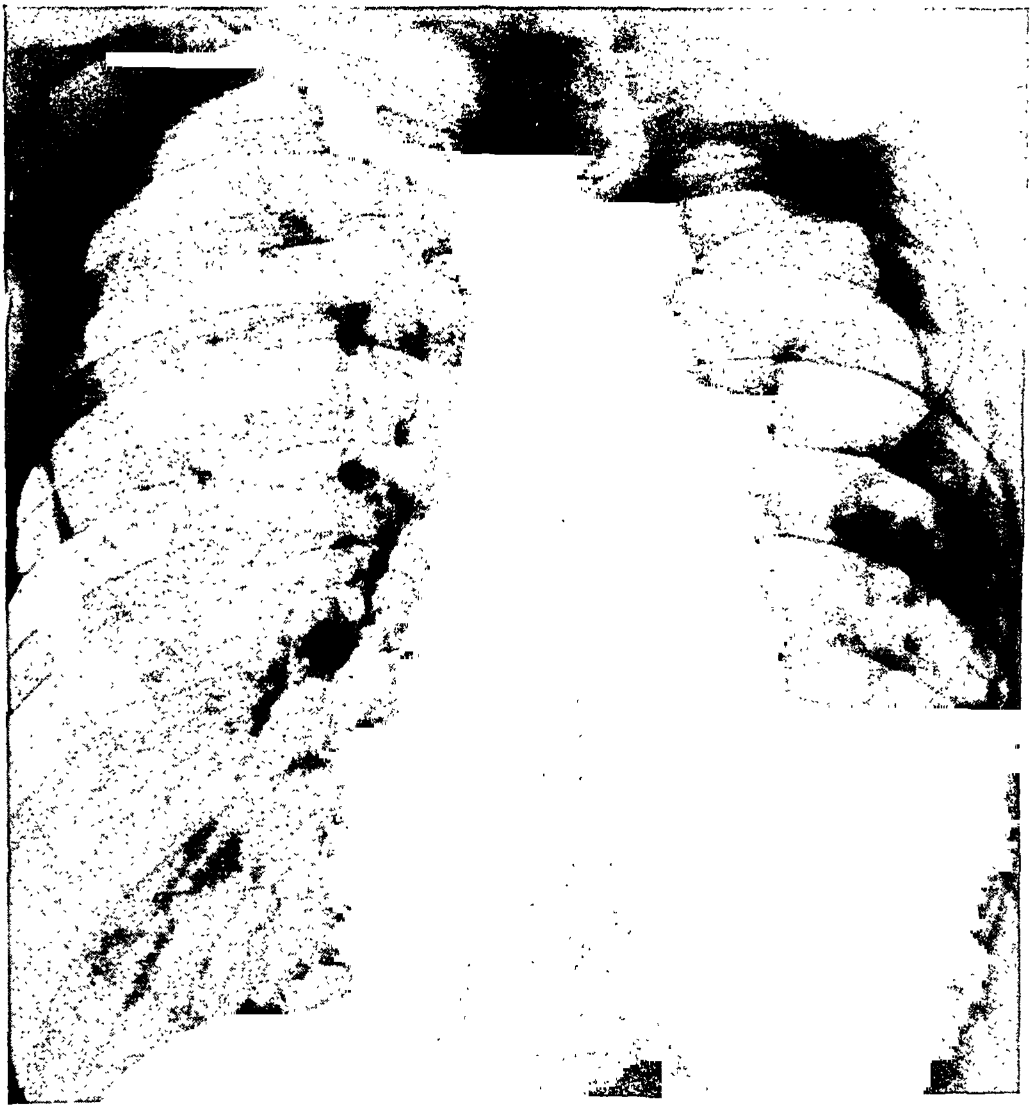


Fig. 8A.—An x-ray taken of a 37-year-old man with a left-sided tuberculous empyema, bronchopleural fistula, and a destroyed lung. Maximal breathing capacity 19 L./min.

walk slowly for 30 meters and was then very short of breath. His arterial oxygen tension was 59 mm. Hg; the carbon dioxide tension 58 mm. Hg, and the pulmonary artery pressure 35/15; mean 25 mm Hg at rest; and 71/72; mean 49 mm. Hg during exercise (75 Kgm/min). He was, however, sputum free and the guinea pig test was negative but he did not perform any work.

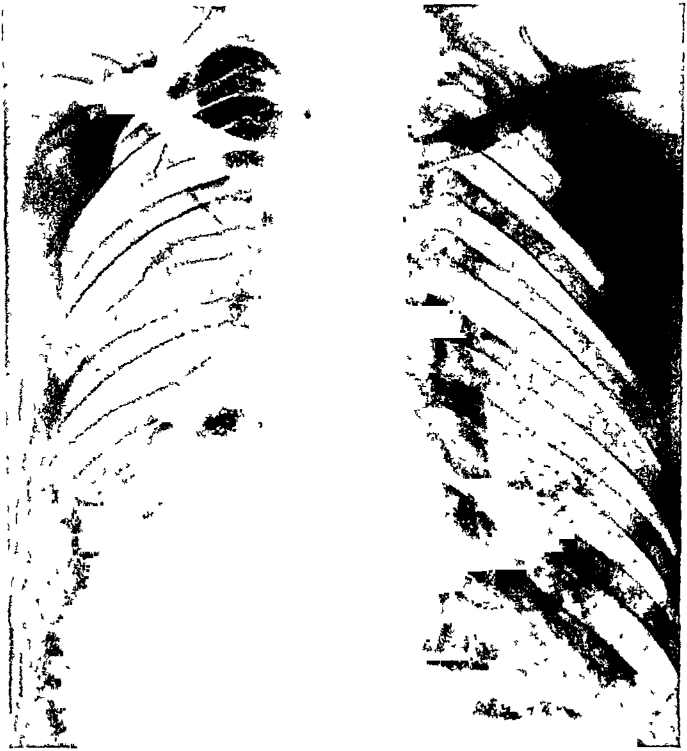


Fig 10A.—An x-ray taken of a 29-year-old man with a cavity under a three-year-old right-sided extrapleural pneumothorax There is, as well, a cavity in the apex of the left lung

The following correlation has been found between the maximal breathing capacity and the patient's own feeling of shortness of breath. Even after a total thoracoplasty, only one-third of the patients had the mediastinum in the midline. In two-thirds of the patients, the x-ray examination showed a dislocation of the mediastinum to the operated side with a correspondent overdistention of the remaining lung.

patients could bring the arm on the operated side up to 170 degrees, 14 patients up to 160 degrees, 11 patients up to 150 degrees, and 5 patients less than 140 degrees.

Pain: In 78 patients (80 per cent), there was no pain connected with maximal arm movements. Eighteen patients complained of some discomfort which in most cases was due to the scapula riding over some prominent rib or rib regeneration. In some patients pain was felt over the lowermost ribs on the side operated upon.

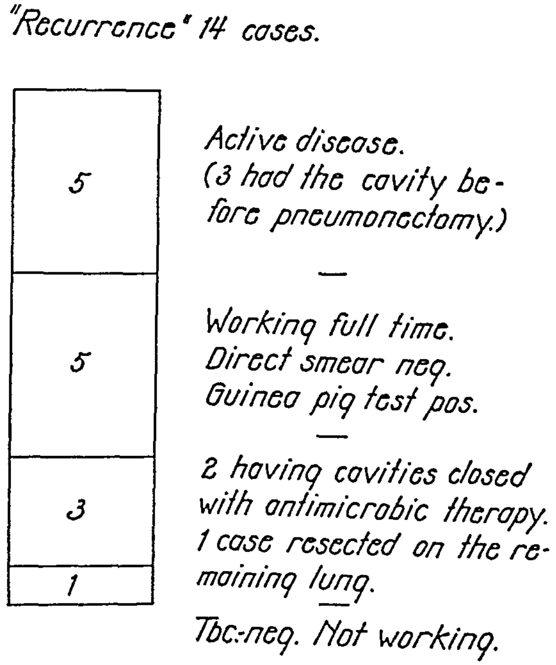


Fig. 9.—Fourteen patients were not "cured."

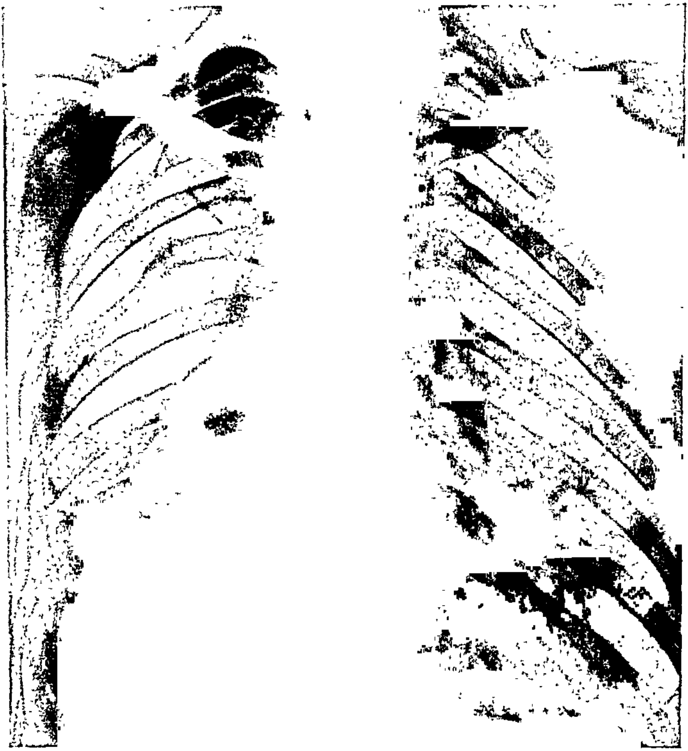
Cough: Sixty-eight patients (70 per cent) were free from cough but 29 had an irritating cough, mostly in the mornings. Seventeen of these patients with a long-standing irritating cough were found to have suture granulomas and the cough disappeared in most of these patients after removal of sutures through the bronchoscope. Many of these 29 patients reported that they had coughed up silk stitches on several occasions.

Dyspnea: Sixty-three patients (69 per cent) were free from dyspnea in their usual activities but 30 patients complained that they were short of breath. The postoperative values for the maximal breathing capacity are shown in Table II. The lowest value was 18 L./min. in a 37-year-old man having gone through a left extrapleural pneumonectomy (Figs. 8*A* and 8*B*). This man could

TABLE II. THE POSTOPERATIVE VALUES OF MAXIMAL BREATHING CAPACITY (MBC) IN LITERS PER MINUTE

MBC	MEN	WOMEN
10-29	2	8
30-49	8	24
50-69	14	20
70-89	11	2
90-109	4	–

walk slowly for 30 meters and was then very short of breath. His arterial oxygen tension was 59 mm. Hg; the carbon dioxide tension 58 mm. Hg; and the pulmonary artery pressure 35/15; mean 25 mm. Hg at rest; and 71/72; mean 49 mm. Hg during exercise (75 Kgm./min.). He was, however, sputum free and the guinea pig test was negative but he did not perform any work.



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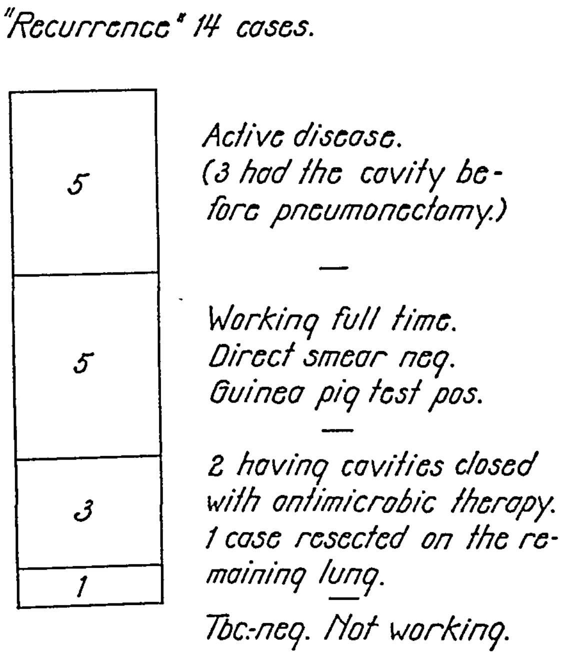

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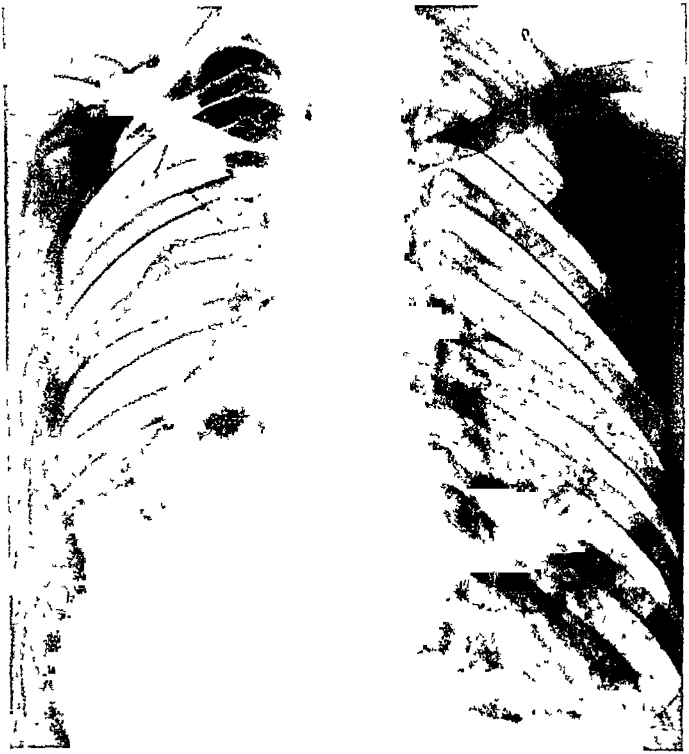

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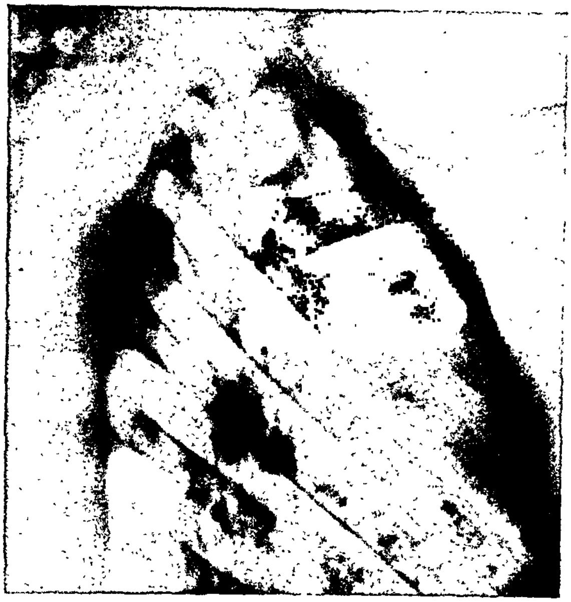


Fig. 10*B*.—This x-ray demonstrates the cavity in the left upper lobe.

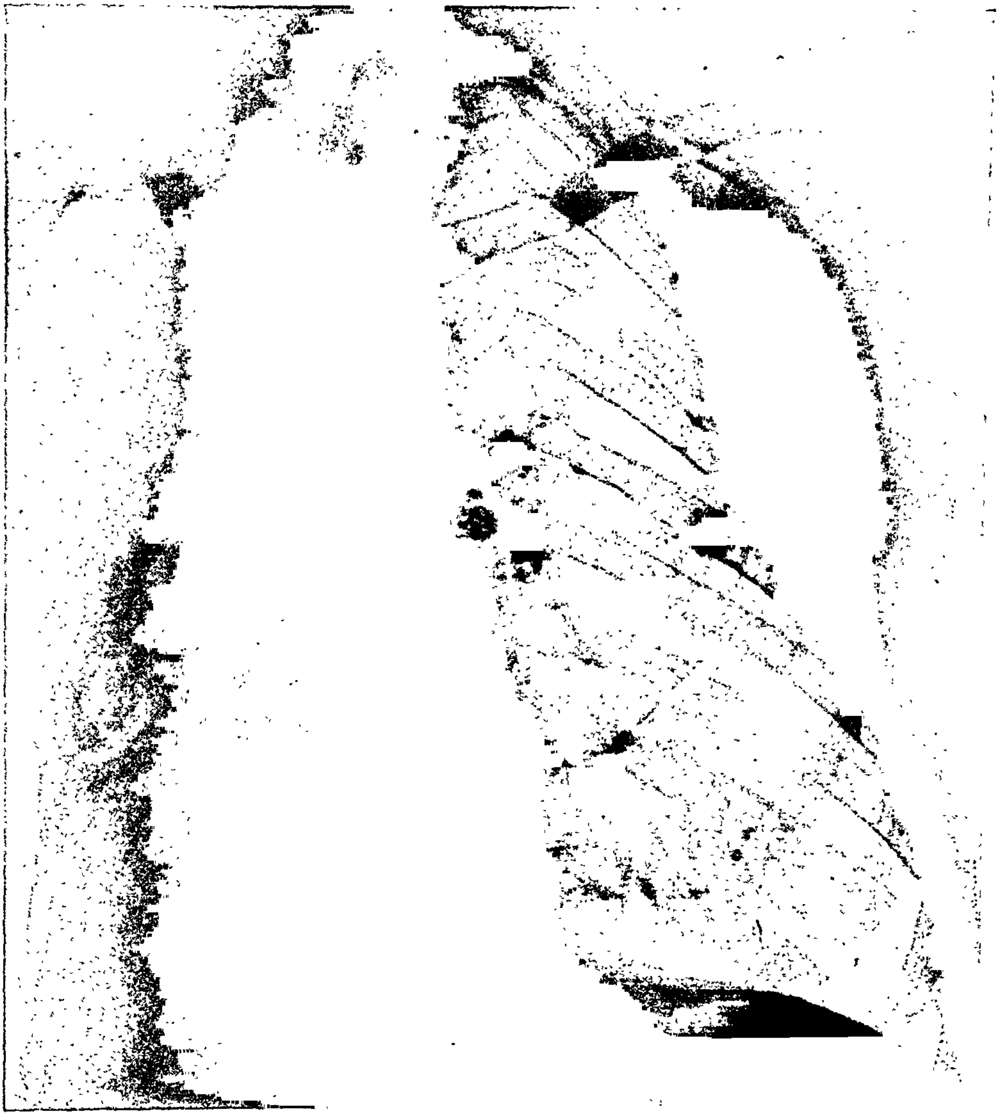


Fig. 10*C*.—An x-ray taken after resection of the right lung (March, 1954) and the apicoposterior and inferior lingula segments of the left upper lobe (March, 1955). Prolonged artificial ventilation was used during the last postoperative course.

TABLE III. THE CORRELATION BETWEEN THE PATIENT'S SUBJECTIVE FEELING OF SHORTNESS OF BREATH AFTER A PNEUMONECTOMY AND FOUND VALUE OF THE MAXIMAL BREATHING CAPACITY (MBC)

	MBC (L/MIN.)	
	MEAN VALUE	RANGE
24 men not feeling short of breath	66.8	96 32
9 men feeling short of breath	48.8	80 18
25 women not feeling short of breath	51.5	78 40
19 women feeling short of breath	36.5	58 20

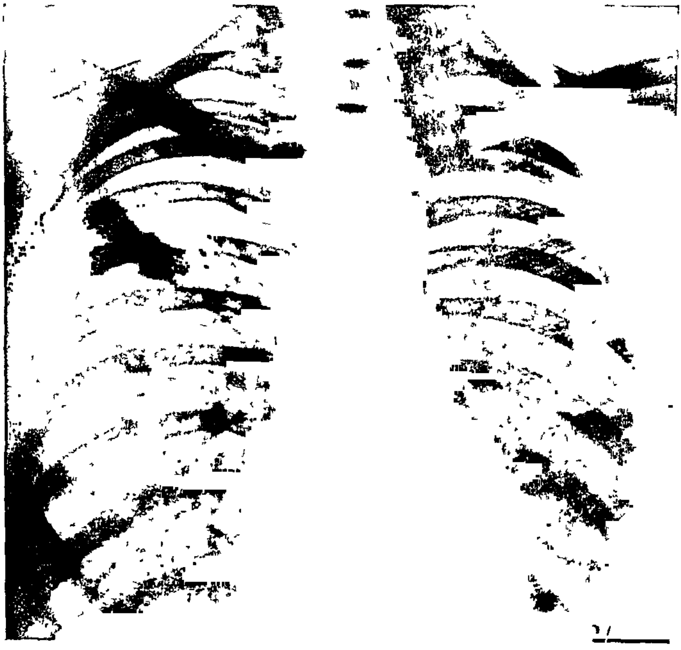


FIG. 11A.—An x-ray of a 22-year-old woman which shows an infiltration with a central cavity in the right upper lobe (1947).

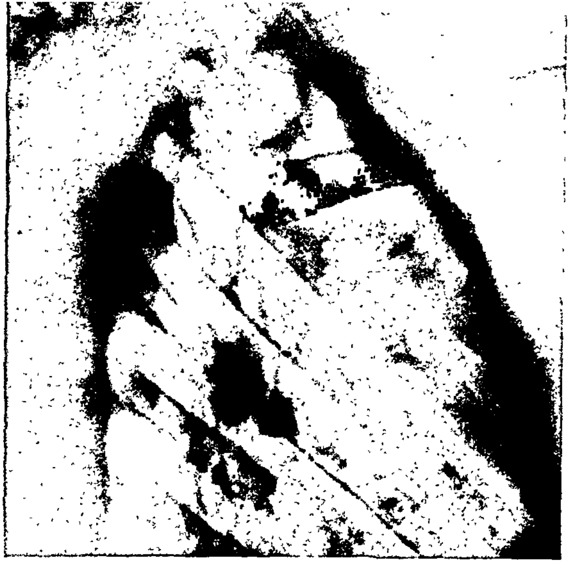
Not "Cured" Patients.—

Fourteen patients were not "cured" by a pneumonectomy (Fig. 9).

Four of these patients had activity in the remaining lung (3 with cavities), none of them were working. The 3 patients with cavities in the only remaining lung had had these cavities at the time of operation.

Five patients had a positive guinea pig test but a negative direct smear and were working full time.

Three patients with bilateral disease had a cavity in the only remaining lung one year after the pneumonectomy. In 2 of these, there was a very good



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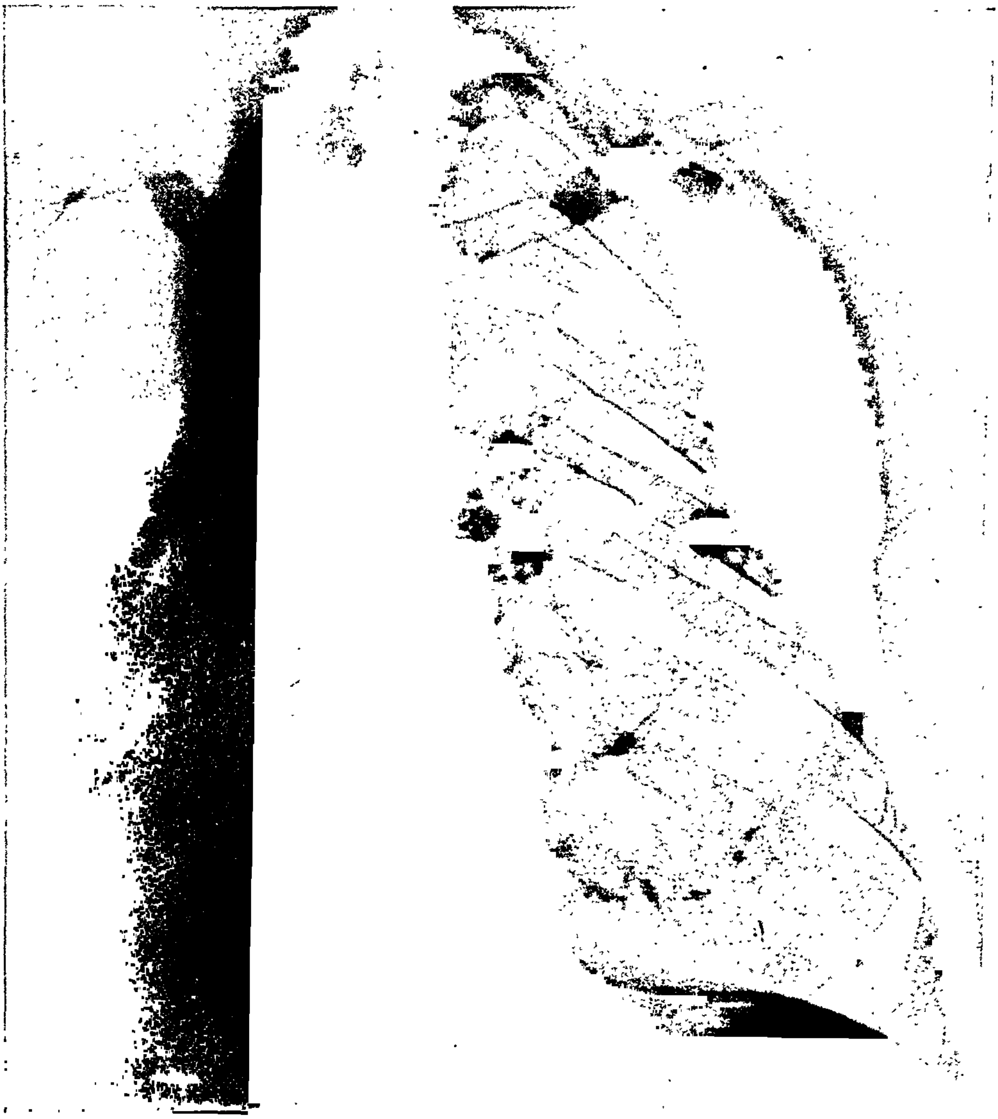

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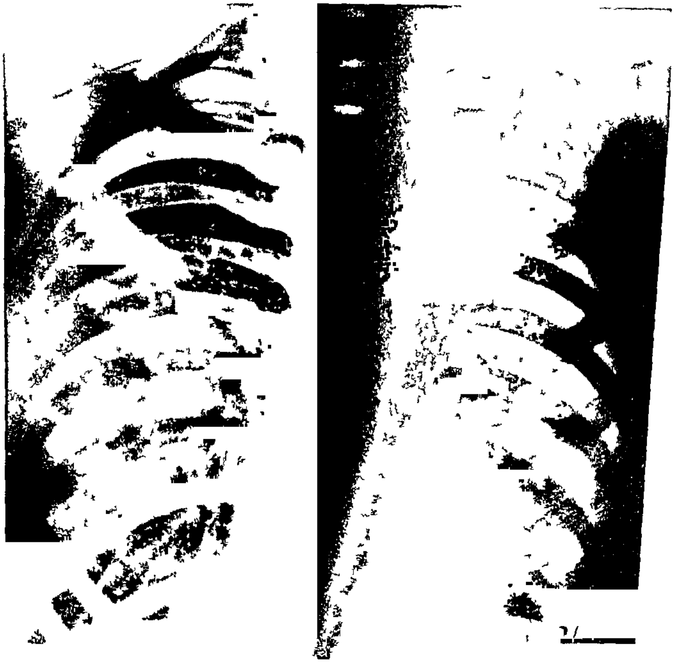

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Three patients with bilateral disease had a cavity in the only remaining lung one year aft [illegible] In 2 of these, there was a very good response to chemotherapy with "closure" of the cavity and the patients were able to return to work. The third case, a 29-year-old man, underwent a right extrapleural pneumonectomy and a 10-rib thoracoplasty. One year later, the apicoposterior and inferior lingula segments of the left upper lobe were resected for a tuberculous cavity. After that operation the patient is in a very good condition, his sputum is negative, and he is going to take up office work. His maximal breathing capacity eight months after the last operation is 59 L./min. (Figs. 10*A*, *B*, *C*).

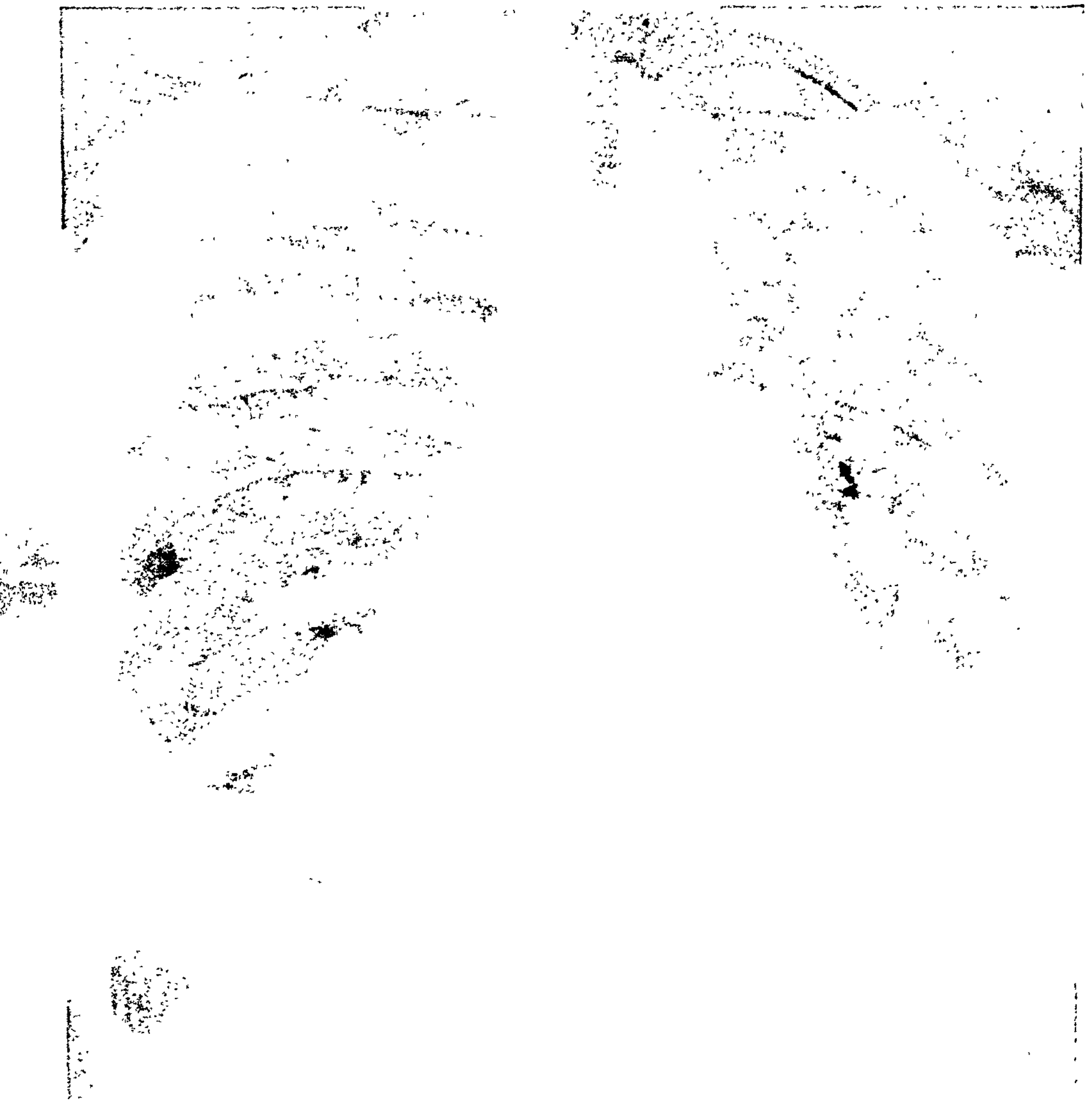

Fig. 11*B*.—After 5 years' right-sided pneumothorax, there was still a cavity in the right upper lobe. On the left side, several cavities necessitated pneumonectomy.

One patient has had ulceration of the main bronchus to the remaining lung with positive sputum three years after pneumonectomy but has reacted well to antimicrobic therapy.

One patient is sputum negative but is very nervous and now, five years after the pneumonectomy, has not yet taken up any work. Her weight is 35 kilograms.

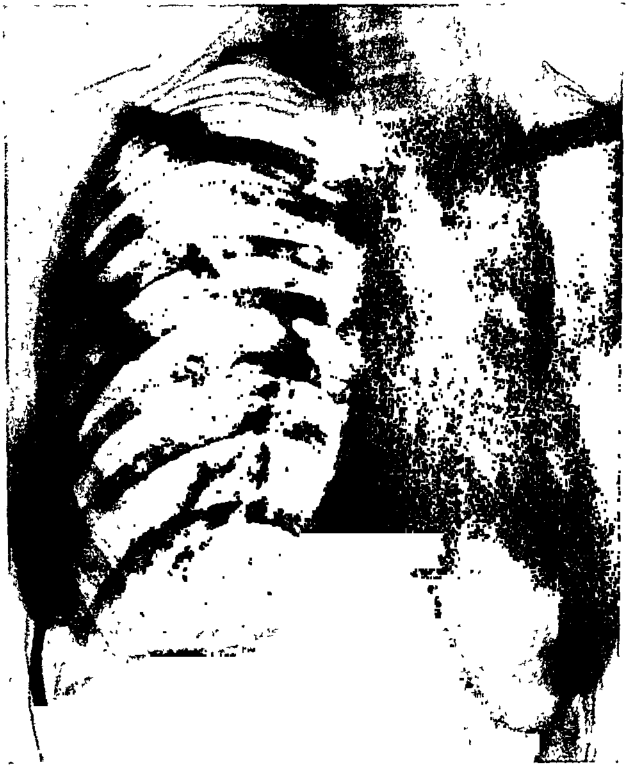

Fig. 11*C*.—An x-ray taken 3 years after the left pneumonectomy. The cavity in the right upper lobe is inspissated and calcified.

THE CONTRALATERAL LUNG AFTER A PNEUMONECTOMY FOR PULMONARY TUBERCULOSIS

It is a general impression that the contralateral lung has withstood the pneumonectomy very well. One 22-year-old woman had a cavity under a five-year-old pneumothorax on the right side when left pneumonectomy and, later, a 10-rib thoracoplasty were performed in two stages. One year after the pneumonectomy, the cavity in the lung was inspissated and calcified and the pneumothorax abandoned (Figs. 11*A*, *B*, *C*). The guinea pig test on sputum and gastric washing was negative and she started to work. Three years after the operation, the tests are still negative, and she is in a very good condition, working full time, newly married, can climb 4 flights of stairs, and has a maximal breathing capacity of 48 L./min. Reactivations, even with cavitation, have reacted well to chemotherapy. Table IV will indicate the condition of the contralateral lung at the time of operation and the result (''cure''-guinea pig test on sputum and gastric washing negative with no active disease at the x-ray investigation).

TABLE IV. THE CONDITION OF THE CONTRALATERAL LUNG AT THE TIME OF OPERATION CORRELATED TO THE RESULT AT THE FOLLOW-UP

CONDITION OF THE CONTRALATERAL LUNG	"CURE"	RECURRENCE
Normal	47	4
Small infiltration	37	5
Infiltration earlier treated by pneumothorax	4	-
Cavity "closed" by conservative treatment	2	-
Cavity "closed" by pneumothorax	3	2
Open cavity	2	3
Open cavity remaining after pneumothorax treatment	1	-
Open cavity under a pneumothorax	1	-
Total	97	14

On the other hand, 14 of the 16 patients that died had had significant tuberculosis, in 6 cases with cavitation on the contralateral lung. The general experience from resections on patients with bilateral tuberculosis has shown that patients with a pneumothorax on the contralateral lung often have difficulties during the postoperative period. The respiratory work for the patient with an old pneumothorax on the contralateral lung is considerably increased. It may be possible for the patient to perform an efficient ventilation and to bring up the secretion for a few days after the operation. Then, the patient is exhausted from the increased respiratory work and the ventilation becomes more and more insufficient with carbon dioxide retention. The immediate risk is therefore considerably higher when the patient has had a pneumothorax on the contralateral lung. The patient may tolerate very well the occlusion of the pulmonary artery on the side to be operated upon for some time. Yet, the respiratory work with expectoration performed with an old pneumothorax lung, will often be too much for the patient after a few days. This is often reported as cardiorespiratory insufficiency in the reports. The death in such cases is often due to carbon dioxide retention. Therefore a resection, especially a pneumonectomy, should not be performed on such patients unless it is possible to take over the patient's respiration with prolonged artificial ventilation during the postoperative period.

The long-term prognosis is also considerably worse in patients having had pneumothorax on the only remaining lung. Two such patients have already died from cor pulmonale after six months and three years, respectively.

SUMMARY

Pneumonectomy is reserved for destroyed lungs whether a bronchial stenosis is present or not. A one-stage procedure with resection and osteoplastic wall thoracoplasty is recommended. If the function of the remaining lung is

impaired by disease or an old pneumothorax, the respiratory work for the patient in the postoperative period is often too great, with carbon dioxide retention as the result Then prolonged artificial ventilation through a tracheostomy is indicated until the patient has regained strength enough to perform adequate ventilation and bring up the secretion Of 111 cases followed 1 to 5 years after operation, 97 patients or 87 per cent are considered "cured" Of the 14 patients with recurrence, 5 are well and working with negative sputum but with a positive guinea pig test on the gastric washing

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HEMORRHAGE FROM FIBRINOLYSIS IN PULMONARY SURGERY

Report of a Case With Study of Coagulation Mechanism

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Boston, Mass.

Though the hazard is now well known, the exact nature and pathogenesis, and hence the best treatment, of the coagulation defects that may develop in the course of operations on the lung are still poorly understood and may not be the same in every case. The present report describes a fatal case in which the clotting defect was studied in some detail.

CASE REPORT

The patient, a 43-year-old Caucasian paper-cutter, was admitted to the Massachusetts Memorial Hospitals on Oct. 15, 1954, complaining of shortness of breath and swelling of the ankles. For approximately one year he had noted a nonproductive cough which he attributed to "bronchitis." Four months before admission he experienced, for the first time, slight dyspnea which became increasingly severe, and ankle edema. He was treated with digitalis and mercurial diuretics with gradual diminution of dyspnea and edema but the cough persisted.

On *physical examination,* the patient was a slender middle-aged man who appeared chronically ill but was in no acute distress. Temperature was 100° F., pulse 100 per minute, respirations 20 per minute, and blood pressure 126/76 mm. Hg. Neck veins were not distended. The trachea appeared to be slightly deviated to the right. Examination of the lungs showed dullness over the right lower lung field anteriorly and posteriorly, above which there were moist râles and diminished breath sounds. The left lung was hyperresonant but free of râles. The heart was not clinically enlarged. There were occasional ventricular extrasystoles. A high-pitched apical presystolic murmur was present. The liver and spleen were not palpable and there was no peripheral edema. Neurological examination was unremarkable.

Laboratory data were as follows: blood urea nitrogen, 15 mg. per cent; fasting blood sugar, 77 mg. per cent; CO_2-combining power, 30.6 meq./L.; chlorides, 98 meq./L.; sodium, 135 meq./L.; and potassium, 5.5 meq./L. Erythrocyte sedimentation rate was 28 mm. in one hour. The hemoglobin was 12.9 Gm. per cent and the hematocrit 40 per cent. The number of leukocytes ranged from 7,800/mm.^{3} to 9,500/mm.^{3}, with essentially normal differential counts. The sputum examination was unremarkable. Circulation time (arm to tongue) was 12 seconds. Venous pressure was 4.5 cm. of saline at rest, 7 cm. during exercise, and 5.5 cm. 2 minutes after exercise. First strength PPD (purified protein derivative) skin test was negative. An electrocardiogram was within normal limits. The laminograms of the chest done on Oct. 18, 1954, showed areas of loculated fluid on the right side. There was a suggestion of a mass at the right hilus, with narrowing of the intermediate and lower lobe bronchi, interpreted as suspicious of tumor. Bronchoscopy demonstrated no abnormalities except for mucosal erythema of the right middle and lower lobe bronchi. Cytologic study of the bronchial aspirate was negative for tumor cells. Thoracentesis was performed on two occasions in October, 1954, with recovery of a total of 700 ml. of serosanguineous fluid, pathologic study of which yielded no evidence of tumor cells. Fluoroscopy of the chest

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**Assistant in Surgery, Boston University School of Medicine, and Resident in Surgery, Massachusetts Memorial Hospitals, Boston, Mass.

revealed minimal excursion of the right hemidiaphragm with no paradoxical motion. Right prescalene lymph node biopsy demonstrated "chronic inflammatory changes" only. The coagulation mechanism was not studied preoperatively, as nothing in his history suggested a hemostatic defect.

Although no tissue diagnosis of malignancy had been possible, the presence of hemorrhagic pleural effusion, together with the laminographic findings suggesting neoplasm, were felt to warrant exploratory thoracotomy, which was performed on Nov. 4, 1954, under general endotracheal anesthesia. Extrapleural dissection was required initially because of the markedly thickened and adherent pleura. A dense fibrous and fibrinous cortex covered both visceral and parietal surfaces. The lung parenchyma appeared unremarkable on cursory palpation and frozen section study of a pleural biopsy showed no evidence of tumor or tuberculosis. A small amount of hemorrhagic pleural fluid was present. In order to examine the lung satisfactorily, as well as to remove the ventilatory restriction secondary to the fibrothorax, visceral and parietal pleural decortication was performed. This proved to be technically difficult and was attended with marked blood loss. However, there was no generalized bleeding. Blood repletion appeared adequate, the patient receiving 2,000 ml. of whole blood during the procedure.

Before the thoracotomy wound was closed, it was noted that the pleural cavity was free of blood clot; no significance was attached to this fact at the time, however. A slow, generalized ooze of blood was seen from all sites of decortication, but did not appear out of proportion to the extent and type of operation.

At the conclusion of the three-hour procedure and after the wound had been completely closed, the blood pressure, previously stable, suddenly became unobtainable. Alarming bleeding was observed from the thoracotomy tubes. Resuscitative measures included the liberal use of whole blood transfusions which were ineffective in raising the blood pressure. The pulse remained relatively slow and forceful. L-norepinephrine was unsuccessful in improving the hypotension. Preparations were made to reopen the chest with the possibility of ligating one or more actively bleeding vessels. However, hematological consultation had been secured at the time of onset of hemorrhage and hastily completed preliminary studies indicated the presence of a coagulation defect, due to fibrinolysis. It was therefore felt that exploratory thoracotomy would be futile. Multiple transfusions with whole blood were continued. The sanguineous drainage in the thoracotomy water-seal bottle showed no tendency to clot and it was observed that unusual oozing occurred from the skin at sites of venipuncture. One unit of plasma and 4 Gm. of fibrinogen were administered intravenously without appreciable effect on the bleeding. Resuscitative measures were continued, including artificial respiration and massive transfusion of whole blood, but all efforts to maintain the patient were unsuccessful and he died four hours after the hemorrhagic tendency first became manifest. The total amount of whole blood administered following the clinical onset of the clotting defect was 5,500 c.c.

Autopsy was performed four hours post mortem. There were hematomas and ecchymoses of the skin. No blood clot was encountered at any point in the vascular system and the heart blood was completely fluid. No blood clot was seen at any site in the fresh thoracotomy wound. The right pleural cavity contained 800 c.c. of dark red, unclotted blood. The right lung showed atelectasis, most pronounced in the middle lobe. The left lung was unremarkable. Examination of the heart showed rheumatic mitral stenosis. There was massive emphysema of the mediastinum and retroperitoneum, with dissection of the air between the leaves of the mesocolon. This was undoubtedly secondary to the decortication, which had been particularly difficult in the region of the diaphragm. Complete gross and microscopic study disclosed no evidence of carcinoma or tuberculosis.

COAGULATION STUDIES

Clotting tests done on a sample of venous blood taken about three hours before death gave the following results. The whole blood clotting time (Lee and White) in two glass tubes was 3½ and 4 minutes [illegible] the presence of a circulating anticoagulant. Good clots appeared completely within 20 minutes' incubation at 37° C. A clot from the same volume (1 ml.) of normal blood, washed in normal saline and suspended in about 0.8 ml. of the patient's serum, was apparently intact at 6 hours at 37° C., but was completely lysed within 24 hours.

The one-stage "prothrombin" test of Quick (using 0.1 ml. each of acetone-dried human brain extract, test citrated plasma, and $\frac{M}{40}$ $CaCl_2$) showed a prolonged clotting time (Table I). The addition to the patient's plasma of normal plasma treated with $Al(OH)_3$ (which contains Ac-globulin but lacks SPCA* and prothrombin) in a proportion of 1:10 had no effect on this clotting time, whereas the admixture of aged normal serum (rich in SPCA but lacking the other factors to which this test is sensitive) shortened it significantly. This suggests that the patient's plasma was deficient in SPCA precursor (factor VII, proconvertin). Prothrombin itself, estimated by the two-stage area method of Biggs and Douglas,[1] was 70 per cent, which is at the lower limit of normal.

TABLE I. DIAGNOSTIC ONE-STAGE "PROTHROMBIN" TIMES WITH PRESUMPTIVE EVIDENCE OF SPCA DEFICIENCY IN PATIENT'S PLASMA

ONE-STAGE "PROTHROMBIN" TIMES (SECS.)				
NORMAL PLASMA	PATIENT'S PLASMA	PATIENT + 10% NORMAL PLASMA	PATIENT + 10% NORMAL Al (OH)$_3$ PLASMA	PATIENT'S PLASMA + 10% OLD NORMAL SERUM
14	23	19	23	17

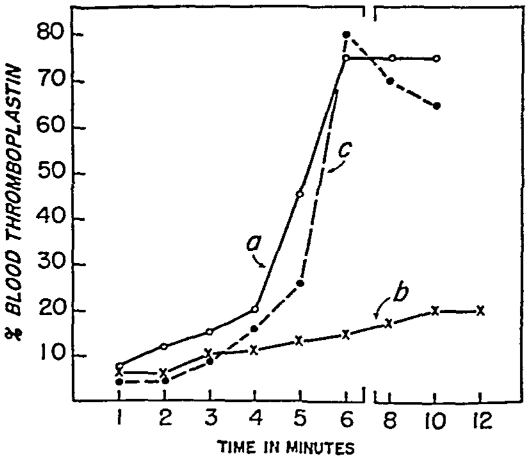

Fig. 1.—Intrinsic blood thromboplastin generated in mixtures of normal platelet suspension with (*a*) normal $Al(OH)_3$-treated plasma and normal serum; (*b*) normal serum and patient's $Al(OH)_3$-treated plasma; (*c*) normal $Al(OH)_3$-treated plasma and patient's serum. (100 per cent represents clotting time in substrate plasma of 10 seconds.)

The blood thromboplastin generation test[2, 3] showed that a potent thromboplastin was generated from a mixture of the patient's serum with normal platelet suspension and normal plasma treated with $Al(OH)_3$, i.e., the patient's serum, in spite of its deficiency in SPCA, had an adequate content of blood thromboplastin components (Fig. 1). On the other hand, when the generating mixture consisted of normal platelet suspension, normal serum, and patient's plasma treated with $Al(OH)_3$, the generation of thromboplastin was significantly impaired. The blood thromboplastin components present in $Al(OH)_3$

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*Serum prothrombin conversion accelerator.

treated plasma are Ac-globulin (factor V, proaccelerin) and antihemophilic globin (thromboplastinogen); since no lack of Ac-globulin could be demonstrated (Table I), it follows that the patient's plasma had less than a normal content of antihemophilic globulin.

Using a modification of Schneider's rapid method for estimating fibrinogen,[4] the fibrin titer of the patient's plasma was 200, not significantly different from the normal plasma titer of 400. By the method of Ratsoff and Menzie, the patient's venous blood contained 194 mg. of fibrinogen per 100 ml., compared with 202 mg. per 100 ml. in normal control blood.

Blood drawn from the pleural cavity, before fibrinogen was given intravenously, did not clot and contained less than 10 mg. of fibrinogen per 100 ml. After the intravenous administration of 4 Gm. of Fraction I of Cohn, the blood from the pleural cavity, still fluid, contained 24 mg. of fibrinogen per 100 ml. Blood from the right atrium, taken four hours after death, was fluid and contained no fibrinogen. Like the pleural blood, it was totally lacking in both Ac-globulin and SPCA, but contained a near-normal amount of prothrombin as estimated by the two-stage area method.

The fibrinolytic activity in the pleural and post-mortem blood was further studied by observing its effect on a standard fibrin clot in the following manner. Solutions of fibrinogen (Fraction I) 0.15 per cent in 0.4 ml. quantities were mixed with 0.8 ml. of 0.85 per cent NaCl buffered with veronal acetate buffer at pH 7.4 which contained various dilutions of the patient's sera and *normal serum to give the final concentrations shown in Table II. The resulting* 0.05 per cent solutions of fibrinogen were clotted by the addition of 0.1 ml. of topical thrombin solution (Parke Davis Co.) prepared in two concentrations: 20 and 500 units per milliliter. (Two concentrations of thrombin were used because thrombin topical itself, in higher concentrations only, is strongly fibrinolytic, and this fibrinolytic action is inhibited by normal serum even in in high dilution. It therefore seemed desirable to observe the behavior of the

TABLE II. LYSIS TIMES FOR STANDARD CLOTS FORMED BY ADDING 0.1 ML. THROMBIN TOPICAL (20 AND 500 UNITS PER ML.) TO 0.05% FIBRINOGEN IN BUFFERED (pH = 7.4) SOLUTION CONTAINING VARIOUS DILUTIONS OF PATIENT'S SERA OR NORMAL SERUM

DILUTION OF SERUM	UNITS OF THROMBIN USED (0.1 ML.)	TIME (MIN.) FOR COMPLETE LYSIS		
		ANTE-MORTEM PLEURAL SERUM	POST-MORTEM HEART SERUM	NORMAL SERUM
$\frac{1}{8}$	2	180	30	no lysis
	50	120	30	no lysis
$\frac{1}{16}$	2	180	60	no lysis
	50	120	20	no lysis
$\frac{1}{32}$	2	180	60	no lysis
	50	30	10	no lysis
$\frac{1}{64}$	2	300	60	no lysis
	50	20	10	no lysis
$\frac{1}{128}$	2	360	180	no lysis
	50	10	10	1,440
$\frac{1}{256}$	2	480	300	no lysis
	50	10	10	960
Saline only	2	no lysis	–	
	50	420	–	

patient's sera toward a standard clot formed by such an excessive thrombin concentration as well as toward one formed by a low but adequate thrombin concentration.) Good and uniform clots formed in every tube, and were observed at frequent intervals for lysis. The time taken for complete disappearance of the clot was recorded (Table II). The serum taken from the pleural cavity before death, as well as that from the right atrium at autopsy, contained a potent fibrinolysin. This was especially pronounced in the post-mortem sample. When the standard clot was made with the lower thrombin concentration, lysis was less rapid in the samples containing the lower concentrations of serum, suggesting that the lytic activity was weakened by dilution in the absence of an adequate antifibrinolysin. However, in the samples cloted by an excess quantity of thrombin, the shortening lysis-time as the serum was progressively diluted demonstrated that the patient's blood did continue to exert some activity against the fibrinolytic action of thrombin topical. At the highest dilutions of serum in this series the lysis-times were the shortest recorded, presumably because of a synergistic lytic effect. It is of interest that these lysis-times (10 minutes) resemble the spontaneous lysis-time of the patient's own clot.

To determine whether the patient's serum was active against fibrinogen as well as fibrin, 0.4 ml. samples each of ante-mortem pleural serum and post-mortem heart serum were mixed with 0.4 ml. of 0.15 per cent fibrinogen solution. It had been intended to test at intervals for residual fibrinogen, but after periods varying from 15 to 23 minutes solid clots formed spontaneously in every tube. Presumably this coagulation was due to persistent thrombin, although it may have been mediated by the fibrinolytic factor itself, since chloroform-treated plasma may have this property.[5] On standing, total lysis of these clots occurred in the post-mortem samples in about 1 hour, and in the ante-mortem samples in 6 to 8 hours. This test was therefore inconclusive. Positive evidence of fibrinogenolysis, using this technique, was subsequently obtained with more dilute samples of the post-mortem serum. The platelets were not studied.

DISCUSSION

Although fibrinolytic activity of varying degree has been found in the blood in many clinical states, its mechanism and significance remain uncertain. The best general review is still that of Macfarlane and Biggs,[6] while Scott and coworkers[7] describe the practical problems of diagnosis and treatment in those surgical cases where it is of clinical importance. Severe bleeding has been ascribed to fibrinolysis in a variety of surgical situations involving shock,[7, 8] but most frequently in operations on the lung.[9-12] In most instances, these patients showed severe fibrinogenopenia, assumed to be due to fibrinolysis. In some cases, however, the evidence for this has not been adequate to exclude a possible alternative cause of fibrinogen depletion, namely, the systemic release of tissue thromboplastin from the operative site causing intravascular fibrin formation and loss, by consumption, of fibrinogen and other clotting factors from the circulating blood. In such circumstances the presence of fibrinolysis, unless it were striking (as in the present case), might well be incidental or secondary since it has been found, without obvious pathologic significance, in many different clinical and experimental conditions.[13-17] The hemorrhagic states with fibrinogenopenia that may occur in abruptio placentae are considered, with good evidence, to be due to thromboplastin release,[18-21] although here also fibrinolysis has been described,[18, 22-25] playing an uncertain and probably variable role. The lung, like the placenta, is a rich source of tissue thromboplastin, and such a mechanism may well be operative in some cases of fibrinogenopenia occurring in the course of thoracic surgery, whether or not excessive proteolytic activity is found in the plasma.

The present case, however, like one patient of Coon and Hodgson[8] and one of Scott,[7] had a normal plasma fibrinogen level in spite of very rapid lysis of the fibrin clot once formed. Any depletion of fibrinogen, if it occurred, must have been slight and restored by transfusion. No clots were found post mortem, and none formed in the blood taken from the pleural cavity before death. Presumably, therefore, adequate clots had formed, but had been lysed before they were hemostatically effective. As with thromboplastin, the source of the fibrinolytic factor or its activator may have been the lung tissue itself.[6, 26] No evidence was obtained that the lysin circulating before death was active against fibrinogen.

The cause of the prolonged one-stage "prothrombin" time, apparently indicating SPCA deficiency, and of the deficiency in antihemophilic globulin, can only be surmised. These clotting factors may have been susceptible to the proteolytic enzyme that destroyed fibrin, but it is remarkable that none of the other factors was similarly reduced. There is no reason to suppose, in view of the negative history and the fact one brother examined had no clotting defect, that the patient was even a mild hemophiliac, though this possibility cannot be disproved. Experimentally, local tissue injury and thrombosis can cause isolated depletion of antihemophilic globulin,[28] presumably from excessive consumption, and intravenous injection of activated blood thromboplastin sometimes has the same result.[27] In this patient, much ineffective clotting must have taken place at the operative site, and antihemophilic globulin may have been consumed in excess of that contained in the transfused blood. Such a mechanism, however, would not explain the SPCA deficiency.

There was a striking difference between the time required for lysis of the patient's own clot (less than 20 minutes) and that necessary for lysis of a normal clot suspended in the patient's serum (more than 6 hours), a difference not due to plasma fibrinogen concentration. Evidently the lysin was much more active when present at the time of actual clot formation than when allowed to act on a preformed clot. A similar observation has been made in fibrinolysis due to excessive concentration of thrombin topical, the lysis being much more rapid when the excess thrombin is used to form the clot than when it is added immediately afterward.[27]

In the circumstances described here—rapid lysis of fibrin without significant depletion of fibrinogen—the administration of antifibrinolysin in the form of concentrated human albumin, as suggested by Scott and his colleagues,[7] may be more important than fibrinogen as a supplement to transfusion with whole blood, preferably fresh, which is always necessary. This emphasizes the importance of rapid diagnostic methods.[4, 7]

SUMMARY

The coagulation mechanism was studied in a [illegible] dying of hemo[illegible] following pulmonary surgery and the findings are [illegible] ref.

the literature. There was no fibrinogenopenia, but rapid lysis by the patient's serum of his own and standard fibrin clots was demonstrated. The plasma was deficient in antihemophilic globulin and SPCA precursor.

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Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-seventh Annual Meeting of The American Association for Thoracic Surgery will be held May 4, 6, and 7, 1957, in Chicago, Illinois. Headquarters will be at the Palmer House.

Requests for Hotel Reservations

These should be mailed directly to Mr Edward Langford, Reservations Manager, Palmer House, Chicago. Please mention this Association, the type of accommodation desired, the date, and approximate hour of arrival and departure. If accommodations are desired elsewhere in Chicago, please communicate directly with the hotel of your choice.

Thoracic Surgery Forum

The Thoracic Surgery Forum will be continued as a special session at the 1957 meeting. The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies, and modified or new surgical techniques. The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferal to the Regular Program.

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper.

All Thoracic Surgery Forum papers will be published together in one issue of the JOURNAL. Maximum length: 3000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts of Papers

Abstracts of all papers for presentation at the 1957 meeting must be received on or before Dec. 15, 1956, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Thoracic Surgery Forum," or "For Regular Program." The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Five, repeat, five copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 600 South Kingshighway, St. Louis 10, Missouri.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. Karl P. Klassen, The Ohio State University, Columbus 10, Ohio, before Dec. 15, 1956.

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions. If the films are well labeled, it will not be necessary for the author to be present for comment.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec. 15, 1956, otherwise the application will be deferred for consideration until the 1958 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. O. T. Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn.

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year. The new letters of recommendation should also be sent to Dr. Clagett, the Chairman of the Membership Committee.

The Journal of
Thoracic Surgery

VOL 32 NOVEMBER, 1956 NO 5

Surgical Forum Issue

A SIMPLE SURGICAL METHOD FOR THE CORRECTION OF MITRAL REGURGITATION USING THE FINGER RING VALVE ELEVATOR

ARVIN S JOHNSON, M D (BY INVITATION)
GROSSE POINTE, MICH

ONE of the problems facing the cardiac surgeon is the development of a simple surgical method for correcting mitral regurgitation Various techniques have been described recently, but the surgical treatment still remains physiologically unsatisfactory

PATHOLOGY OF MITRAL REGURGITATION

Upon careful gross examination of one hundred necropsy specimens of hearts with residual rheumatic mitral valvular lesions, the regurgitant defects were found constantly in the posterior leaflet of 70 per cent of the hearts with combined lesions (stenosis and insufficiency) and those with purely insufficient valves The chordae tendineae in the area of leaflet deformity were shortened and thickened The edge of the involved leaflet was hyalinized, calcified, and curled under

METHODS OF DEMONSTRATING DEFECTS

Using the hydrodynamic technique, the presence of an existing physiologic defect can be easily and accurately located by palpation and direct vision (a) with a finger in the left atrium and water under pressure in the left ventricle, the regurgitant jet is palpable, (b) by excising the left auricular appendage of the necropsy specimen, a more accurate localization of the mitral defect can be made by direct vision A jet of water can be seen squirting through the defective leaflet whenever present, using the water under pressure technique

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From the Department of Surgery (Cardiovascular) Bon Secours Hosp. Grosse Pointe Michigan

Read at the Thirty sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach Fla May 7 to 9 1956

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From the Department of Surgery (Cardiovascular), Bon Secours Hosp., Grosse Pointe, Michigan.

Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

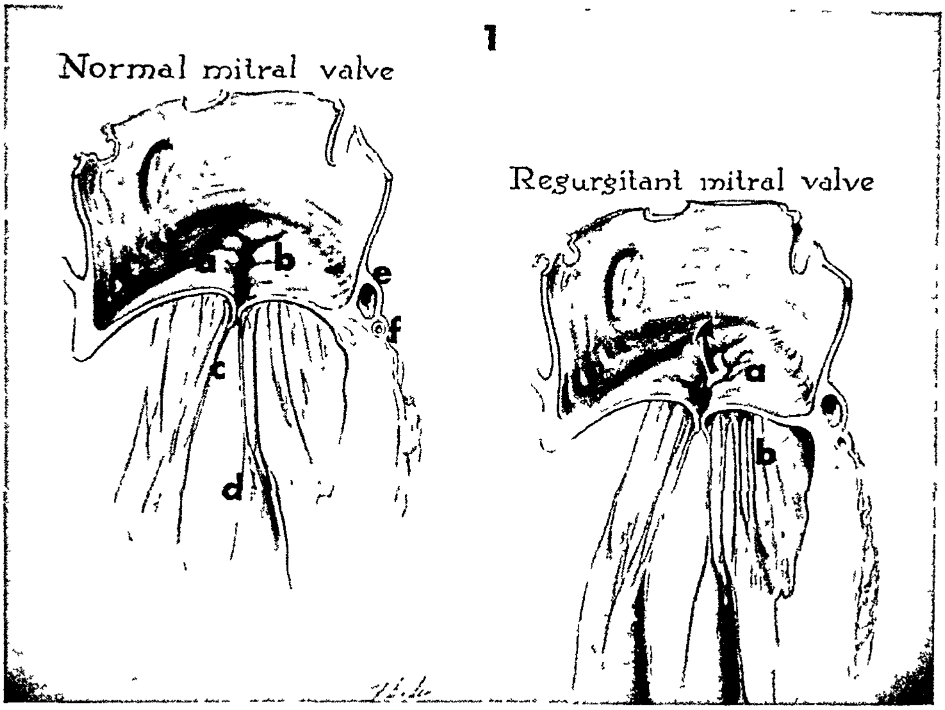

Fig. 1.—Left: Normal mitral valve. *a*, Anterior leaflet. *b*, Posterior leaflet. *c*, Chordae tendineae. *d*, Papillary muscles *e*, Coronary sinus. *f*, Left circumflex coronary artery.

Right: Regurgitant mitral valve. *a*, Area of defect edge of the posterior leaflet. *b*, Shortened and thickened chordae tendineae in the area of defective valve.

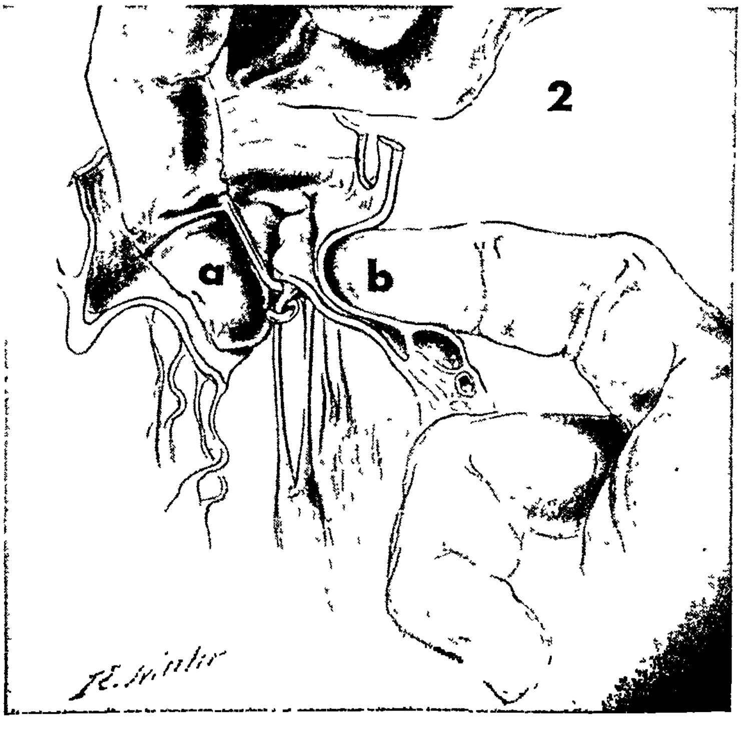

Fig. 2.—The first surgical step in correcting the regurgitation. *a*, Index finger with the ring valve elevator placed around the chordae tendineae at point of insertion into the valve. *b*, Assistant's finger invaginating the posterior atrial wall toward the internally elevated lip of the posterior mitral leaflet.

SURGICAL METHOD OF TREATMENT

Based upon the knowledge that approximately 70 per cent of the mitral lesions are located in the posterior leaflet, a simple surgical method for the correction was designed. The valve is first explored with the index finger of the left hand. If the defect is palpated and localized in the posterior leaflet, the exploring finger is withdrawn. The ring (hook) elevator is then fitted onto the index finger of the left hand and reinserted into the left atrium. The hook end of the ring is placed around the chordae tendineae in the valve area where the edge of the posterior leaflet is curled under. The edge of the curled lip of the valve is then elevated toward the posterior wall of the atrium by stretching the chordae tendineae. The assistant with his finger or a curved Kelly forcep invaginates the posterior atrial wall toward the internally elevated posterior mitral leaflet. Two to three interrupted No. 2-0 silk sutures fix the edge of the defective leaflet to the posterior wall (Figs. 1-4). A second row of interrupted silk sutures is next placed to take the tension off the first row of sutures. A reinforced posterior mitral leaflet has now been constructed. It is semirigid as far as flexibility is concerned. The anterior and medial mitral leaflets become the only freely moving parts of the valve. The mitral valve has now been made physiologically competent. The regurgitant jet is completely absent as a result of a newly reconstructed posterior mitral

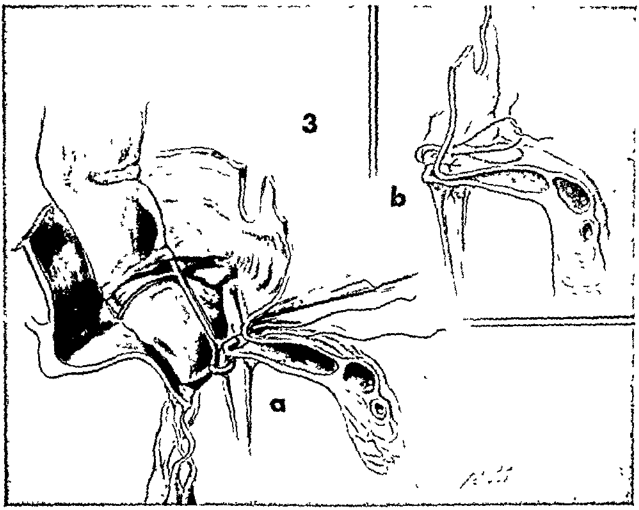

Fig. 3.—The second surgical step in repairing the regurgitant valve. *a*, Placing the first row of silk sutures fixing the edge of the valve to the posterior atrial wall *b*, Sutures being tied in place.

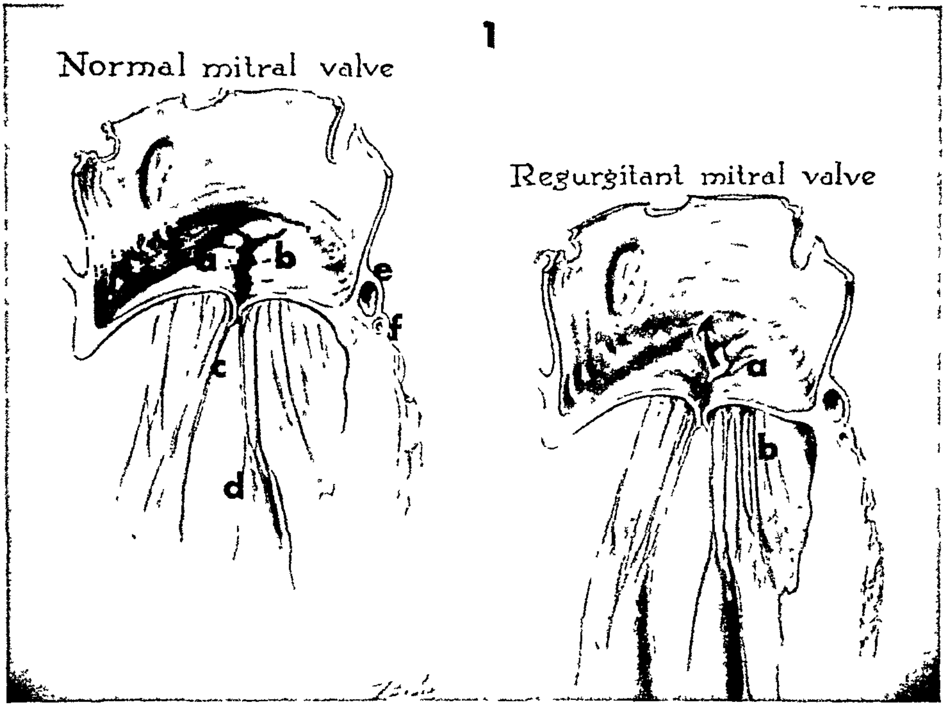

Fig. 1.—Left: Normal mitral valve. *a*, Anterior leaflet. *b*, Posterior leaflet. *c*, Chordae tendineae. *d*, Papillary muscles. *e*, Coronary sinus. *f*, Left circumflex coronary artery.

Right: Regurgitant mitral valve. *a*, Area of defect edge of the posterior leaflet. *b*, Shortened and thickened chordae tendineae in the area of defective valve.

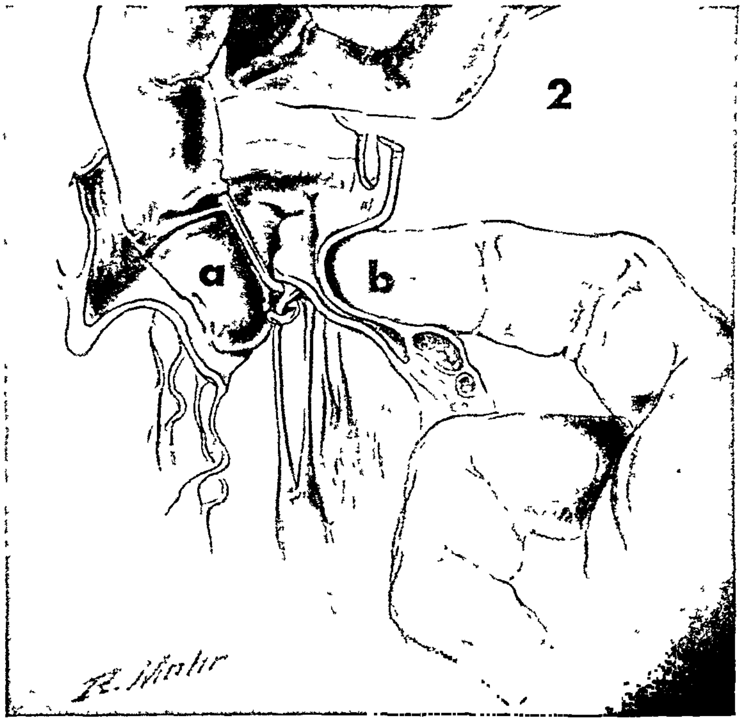

Fig. 2.—The first surgical step in correcting the regurgitation. *a*, Index finger with the ring valve elevator placed around the chordae tendineae at point of insertion into the valve. *b*, Assistant's finger invaginating the posterior atrial wall toward the internally elevated lip of the posterior mitral leaflet.

SURGICAL METHOD OF TREATMENT

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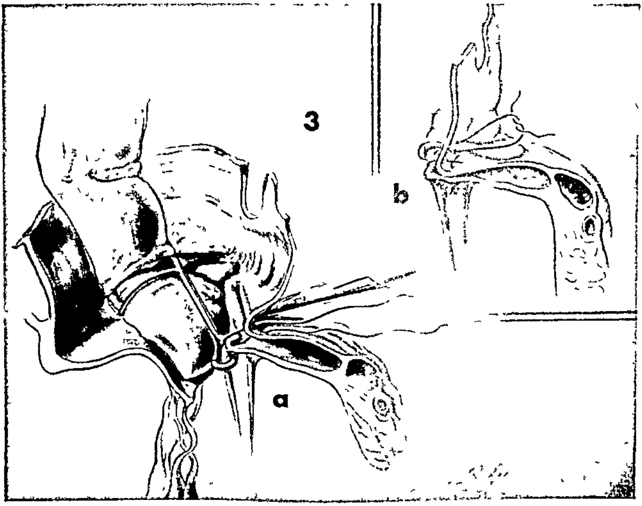

Fig. 3—The second surgical step in repairing the regurgitant valve. *a*, Placing the first row of silk sutures fixing the edge of the valve to the posterior atrial wall *b*, Sutures being tied in place.

leaflet. This technique has been tried and tested many times in the exper ments in which hearts with residual rheumatic deformities encountered a necropsy were used.

The surgical technique for the correction of incompetent mitral valve as described can be used for the "blind cardiovalvoplasty" and is equall successful for the "open cardiovalvoplasty" when a mechanical heart pum oxygenator is employed to by-pass the left side of the heart. The surgica steps for the correction of existing valvular incompetence remain the sam when the "blind" or "open" techniques for approaching this problem ar employed.

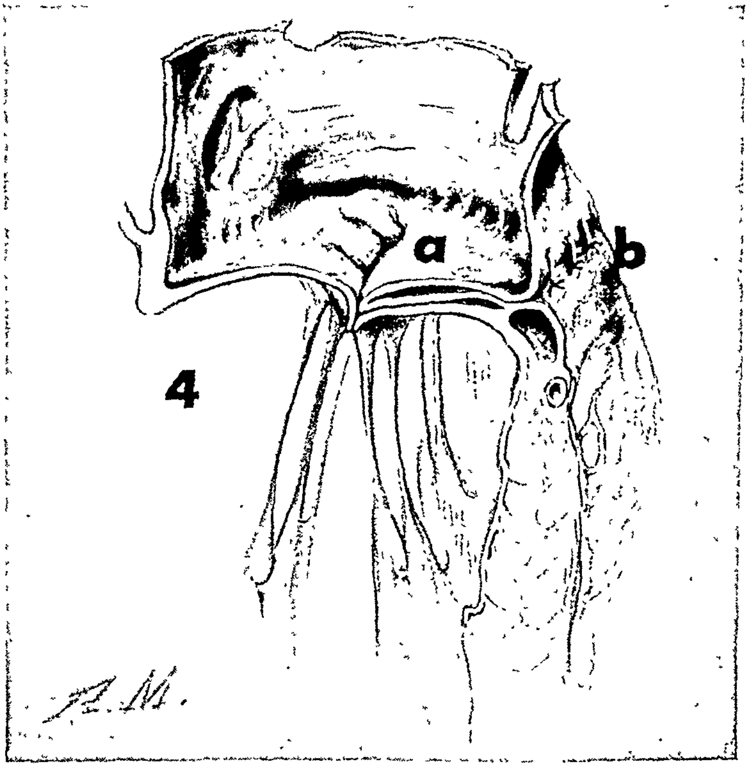

Fig. 4.—The third and final surgical step in repairing the regurgitant valve. *a*, Reinforce and reconstructed posterior leaflet. *b*, Second row of interrupted silk sutures.

CLINICAL APPLICATION

Clinically the finger ring valve elevator has been successfully tried in cases. Three of the patients had the combined mitral lesions (stenosis an regurgitation). These patients obtained excellent results. Of the remainin 3 patients who had pure mitral regurgitation, 2 showed good clinical improvement and the third obtained only fair results. One patient with tricuspid regurgitation was also operated upon. The valve was only partiall repaired during the operation with only temporary improvement. A detailed report on these clinically tested cases is being prepared for later publication.

SUMMARY

1 Description of a simple surgical method using the finger ring valve elevator for correcting mitral regurgitation is presented

2 The clinical application of the surgical technique is briefly discussed

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FURTHER EXPERIENCES WITH THE METHOD OF CONTROLLED UNILATERAL PULMONARY ARTERY OCCLUSION IN THE STUDY OF LUNG FUNCTION

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IN 1951, Carlens, Hanson, and Nordenström[1] published the first report on unilateral occlusion of the pulmonary artery in dog and man, utilizing a double lumen, balloon-tipped cardiac catheter. In 1953, a preliminary report on the use of this method in the study of lung function was made by us.[2] In the five years since the original report of Carlens and his associates, the number of cases which have been studied by the Stockholm group,[3, 4] Sloan and his associates at the University of Michigan,[5] Brofman and his associates in Cleveland,[6, 7] and in our own series has become sufficiently large so that definitive conclusions may now be drawn from this method of investigation.

The purpose of this report is to give the results of our continuing experience with this method and, second, to attempt to evaluate the present status of the study in the light of the collected series. Bagger, Carlens, Hanson, Malmstrom and Uggla have recently reported detailed studies on 109 patients, and more recently the number of cases studied by these investigators is now over 150, and there has been no serious accident.[8] Sloan and his associates reported studies on 18 patients at this meeting one year ago, and they have now studied over 25 patitents.[9] Brofman and his associates[7] have now performed studies on approximately 100 patients, with particular emphasis not only on pulmonary function study, but also on the study of pulmonary hemodynamics.

PRESENT SERIES

Unilateral pulmonary artery occlusion has now been carried out by us in 35 patients. In five instances, passage of the catheter into the desired branch of the main pulmonary artery could not be accomplished. In 4 of these cases, the cause was apparent at operation, in that the pulmonary artery or the superior vena cava was either compressed or distorted by metastatic carcinoma in the mediastinum. In the fifth case, no apparent cause for the failure could be found. In the group of 35 patients in whom studies were carried out, 27 had carcinoma of the lung, 4 had inflammatory pulmonary lesions, 2 had bronchiec-

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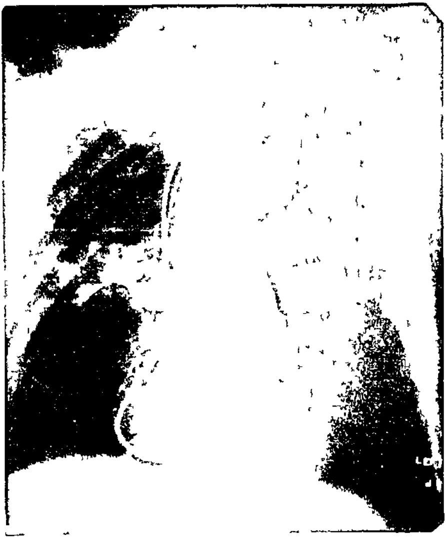
tasis, one had a large right upper lobe cavity of undetermined etiology, and one had berylliosis and severe rheumatic heart disease The youngest patient studied was 37 years of age and the oldest was 73 years of age, with an average age of 61 years. With only a few exceptions, all were patients with poor or borderline pulmonary reserve or associated cardiovascular abnormalities.

METHODS

The procedure used was essentially that as previously stated in the first published article[2] However, with our continuing experience, changes in technique have occurred with some alterations and refinements In the earlier experiments, we used a double lumen catheter with the recording lumen either proximal or distal to the occluding balloon. With this type of catheter, it was necessary to pass a second regular cardiac catheter into the pulmonary conus when pressure recordings both proximal and distal to the balloon were wanted (Fig. 1). Recently, however, we have been using a 125 cm. triple lumen cardiac catheter with recording lumina both proximal and distal to the balloon (Fig. 2).* The use of this single catheter has greatly facilitated the procedure (Fig. 3).



st of a 66-year-old man with a large right upper lobe
cavit ly in the series and two catheters were passed; the double
lumen recording orifice distal to the balloon The second con-
vent lliliters of 35 per cent Diodrast
was ur minutes prior to this roent-
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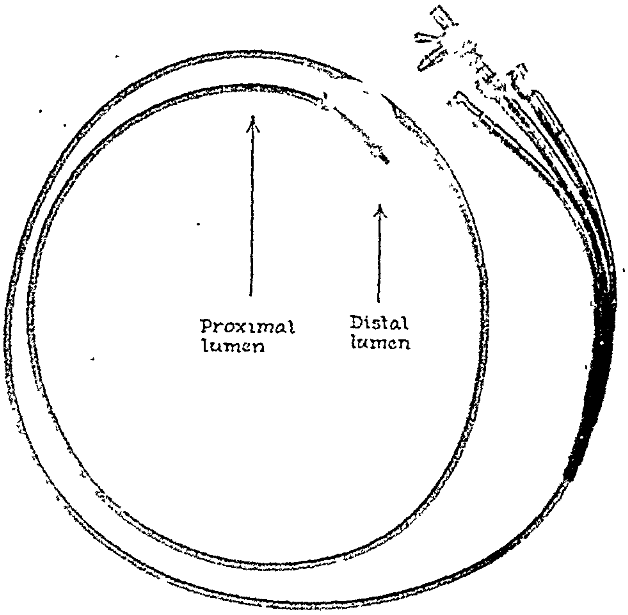
*Obtained from U S Catheter and Instrument Corporation, Glens Falls, N Y earlier cases, it was at times very difficult to place the catheter selectively in the right or left pulmonary artery. As we have gained more experience, however, this is much more readily accomplished. Catheterization of the right or left artery, selectively, has usually taken from ten minutes to one hour and fifteen minutes. In the last 10 cases, using the triple lumen catheter, successful placement has not taken longer than twenty minutes. In the earlier cases, 50 mg. of heparin was given as soon as the catheter was placed in the correct position. However, this practice is no longer felt to be necessary and we have had no difficulty with clotting. Once the cardiac catheter is in position and recording, the femoral artery is rapidly cannulated. All four channels of the Poly Viso electromanometer are thus utilized—one for the continuous electrocardioraphic tracing, one for pulmonary artery pressures proximal to the balloon, ne for pulmonary artery pressures distal to the balloon, and one for coninuous femoral artery pressures. With the catheter in position, occlusion of he artery could be carried out at will.



ig. 2.—Triple lumen, 125 cm., No. 10½ cardiac catheter with recording lumina both proximal and distal to the occluding balloon.

We have abandoned occlusion of the corresponding main-stem bronchus with the Carlens-Stille endotracheal catheter, since we have not felt that this procedure gave us any significant information by the methods used.

Technical Difficulties Encountered With the Method.—

1. As previously stated, passage of the catheter into the desired position has been, at times, difficult. The double and triple lumen catheters cannot be manipulated with the same ease as the ordinary single lumen cardiac catheter. The triple lumen catheter is a No. 10½ cardiac catheter and it has a recording

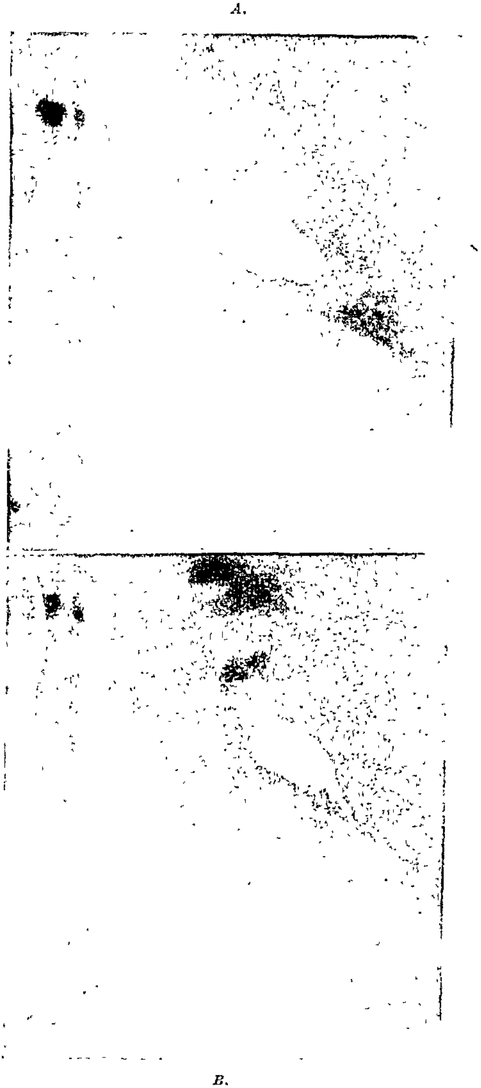


Fig. 3.—Roentgenogram of chest of a 73-year-old man with a carcinoma of the lung. The triple lumen catheter is in the left pulmonary artery. Nine milliliters of Diodrast was used to inflate the balloon before complete occlusion was obtained as evidenced by the change in the contour of the distal tracing, the change in pressure, and the alteration of the gas analyses (see *Fig 6*).

A, Catheter in left pulmonary artery. *B*, Catheter in lobar artery.

lumen both proximal and distal to the occluding balloon. With the use of this catheter we have been enabled not only to record pressure and obtain blood samples for gas analyses both proximal and distal to the inflated balloon, but also to inject substances distal to the inflated balloon. The occurrence of extra systoles, as the large catheter impinges on the right ventricular wall, is almost an invariable accompaniment. However, these arrythmias will disappear immediately upon moving the tip of the catheter. Further mention is made of this.

2. While the balloon could be inflated with ease with the use of 35 per cent Diodrast, withdrawal of the Diodrast when it was desired to deflate the balloon was at times painfully slow, though always accomplished. Between 6 to 10 ml. of 35 per cent Diodrast was used to inflate the balloon. Perhaps the use of Umbradil or Urokon would be better when roentgenograms are desired. If roentgenograms are not desired, inflation is accomplished with saline solution and it may be easily withdrawn.

Complications.—

1. An elevation of the temperature within one to three hours after conclusion of the procedure has occurred in approximately 75 to 80 per cent of the cases. Chills have occasionally preceded the temperature rise. Usually the temperature elevation has been in the range of 101° to 102° F. but on two occasions has been 105° F. In almost all instances, the temperature has returned to normal in one to four hours, and this complication has not been a serious problem. The cause for the temperature elevation is not immediately apparent. Blood cultures have been negative and strict aseptic technique has been employed. Pyrogens in the infusion fluid may have been responsible but this reaction has not generally occurred after routine cardiac catheterization, and great care has been taken to change the fluid at frequent intervals. The possibility that the occlusion of the vessel might in some way be related to the pyrogenic reaction has been considered, but chills and fever have occurred in patients in which the catheter could not be put in the correct position for inflation. Perhaps the one constant relationship was that chills and fever were more likely to occur in those cases in which difficulty was encountered in placing the catheter and repeated manipulation of the catheter was necessary. As stated, however, this complication was never of serious proportions.

2. Ventricular extrasystoles occurred almost invariably during manipulation of the catheter as it passed through the right ventricle. Normal sinus rhythm immediately returned following withdrawal of the catheter into the right auricle. Once the catheter was in position in the pulmonary artery, extrasystoles did not occur. This complication was of no significance with the possible exception of one case in which auricular fibrillation ensued as the study was completed. Rapid digitalization was accomplished and two days later this patient underwent an uneventful pneumonectomy. The case is presented in detail.

Case Report.—W. W., G.H.U.P. 217719, a 66-year-old man, was admitted to the hospital with hemoptysis of four months' duration. Roentgenograms of the chest revealed a mass lesion in the right hilar area. Bronchoscopy was performed and a positive Papanicolaou was obtained. The vital capacity and maximum breathing capacity were within essentially normal limits. VC was 3,330 cc (calculated normal = 2,885) and MBC was 90 L per minute (calculated normal = 109 L per minute). Catheterization studies were carried out. The study went well and rapidly and was completed in about one and one half hours. There were a few extrasystoles as the catheter passed through the right ventricle but nothing unusual. Immediately following withdrawal of the cardiac catheter, while the continuous electrocardiographic tracing was being made, it was noted that the patient suddenly began having auricular fibrillation. Immediate digitalization was carried out and he was rapidly controlled. Forty-eight hours later thoracotomy was performed. He was *found to have a carcinoma of the lung and metastases were present in the mediastinal* lymph nodes. A radical pneumonectomy and excision of the mediastinal nodes in the hilum and along the trachea were carried out. He withstood the operative procedure very well, and his postoperative course was entirely benign. He was discharged from the hospital without digitalis, on the tenth postoperative day.

3. A single major complication has occurred following the procedure. Although there is reasonable doubt as to whether it was a direct result of the procedure, it is nonetheless considered as a complication. The case is presented in detail.

CASE REPORT.—G.H.U.P. 224660. A 38-year-old man was admitted to the hospital with severe dyspnea and recurring bouts of cyanosis. The patient was well and carrying on his occupation of a garbage collector without any difficulty until four months prior to admission. At that time, while loading a truck he suddenly became extremely short of breath, began to perspire profusely and had severe pain in the lower chest and upper abdomen. He was immediately taken to a hospital elsewhere where he was noted, also, to be cyanotic. He was placed in an oxygen tent and treated supportively with only minimal improvement. He was transferred to the Graduate Hospital of the University of Pennsylvania approximately ten days after onset of his illness. Examination at this time revealed an acutely ill man who became severely dyspneic and cyanotic on only slight exertion. Uncontrolled auricular fibrillation was present. There was cardiac enlargement and an apical systolic murmur, felt by the cardiologists to be consistent with a diagnosis of rheumatic heart disease with mitral insufficiency. Roentgenograms of the chest, in addition to revealing cardiac enlargement, showed obliteration of the right costophrenic sulcus due to a small effusion or a pleural thickening and a fine nodular infiltration throughout both lung fields. In view of the clinical history of breaking fluorescent lamps in the garbage, it was felt that the pulmonary changes were consistent with a diagnosis of berylliosis.

Since there was no history of rheumatic fever and since chamber analysis of the heart revealed not only a left auricular enlargement but also an enlargement of all cardiac chambers, it was felt that the cardiac findings might also be on the basis of the pulmonary pathology or perhaps on the basis of some congenital defect. Studies performed were as follows: The PPD test was negative. The iodine uptake was normal. The timed vital capacity was 88 per cent of normal. Blood gas analyses from the femoral artery revealed a pCO_2 of 43, an arterial O_2 saturation of 83 per cent and a pH 7.43. Intercostal pulmonary biopsy was carried out and revealed marked congestion. The specimen was analyzed for beryllium content and this was found to be significantly elevated. Routine cardiac catheterization was requested primarily to determine the presence of a possible congenital anomaly, but in view of the pulmonary findings it was felt that studies proximal and distal to an occluding balloon in the pulmonary artery might be revealing (Fig. 4).

Cardiac catheterization was carried out nine days after digitalization was instituted although at the time of study the heart was still fibrillating. A No. 8 double lumen cardiac catheter was rapidly passed through an arm vein into the right pulmonary artery and a second No. 5 cardiac catheter was passed into the pulmonary conus in order to allow for recordings both proximal and distal to the occluding balloon. Studies were then made with the balloon occluded (see below), and following completion of this, the routine pressures and blood samples were taken from the pulmonary artery, right ventricle, right auricle, and superior vena cava. There was no evidence of congenital anomaly either from the *passage of the catheter, or from the results.* *Studies did, however,* reveal a marked elevation of the pulmonary capillary pressures and elevation of both the pulmonary artery and right ventricular pressures.

Pulmonary capillary pressure = 90/40 - corrected mean 30
Pulmonary artery = 80/10 - corrected mean 28
Right ventricle = 74/10 - corrected mean 24
Right auricular = 20/8 - corrected mean 8
Superior vena cava = corrected mean 10

The findings were felt to be consistent with severe mitral stenosis.

The study took one hour and forty-five minutes and, although the patient perspired rather profusely during it, he tolerated it well. There was no appreciable elevation of the temperature immediately postcatheterization, and he was able to be up and about soon after returning to his bed. About twelve hours after catheterization, in the middle of the night, he fell out of bed and, on examination, was found to have a right sided hemiplegia.

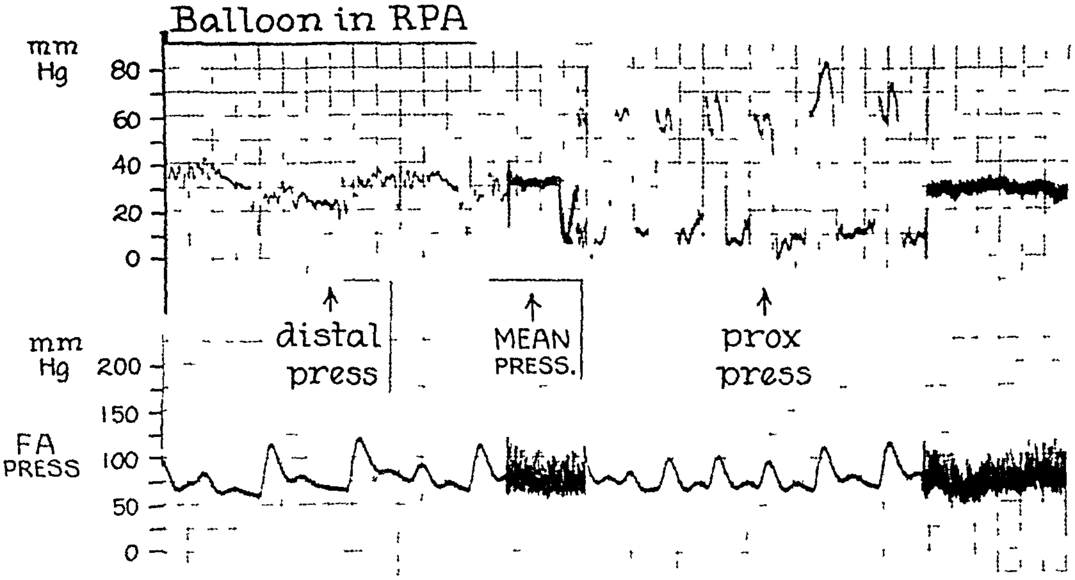


Fig. 4.—Catheterization studies on a 38-year-old man with berylliosis and severe mitral stenosis. The right pulmonary artery (RPA) was occluded by the balloon. The upper tracing is from the pulmonary artery, the lower from the femoral artery (FA). In this instance, proximal and distal pressures were made on the same channel. Note the change in the character of the tracing as recorded distal and proximal to the occluding balloon. Note that the mean pressures both proximal and distal are essentially the same.

He was seen by a neurological consultant who felt that he had had a cerebral vascular accident on the basis of an embolic or thrombotic episode involving a branch of the middle cerebral artery. He was placed on heparin and improvement gradually occurred. After approximately three months, good function returned to his right leg, but the upper extremity remained impaired.

While it is questionable whether or not the catheterization was related to the subsequent episode, we nonetheless feel that it should be considered as a complication. He perspired profusely during the procedure, and it is conceivable that hemoconcentration occurred with an increased thrombotic tendency. We feel the study was justified and, as a result of it, the diagnosis was established.

RESULTS AND DISCUSSIONS

Our investigations utilizing this method of study have been along two general lines (1) study of lung function and pulmonary physiology and (2) the study of pulmonary embolism, which is discussed in detail elsewhere[10, 11]

A *Pulmonary Artery Pressures*—Occlusion of the right or left pulmonary artery was carried out in this group of patients for between twenty and sixty minutes, with an average occlusion time of forty minutes No attempt was made to continue occlusion for longer than one hour In some cases occlusion would be carried out in a lobar artery for twenty minutes or more and then the balloon would be deflated, the catheter gently withdrawn into the main branch of the pulmonary artery, and the balloon again inflated for twenty to twenty five minutes

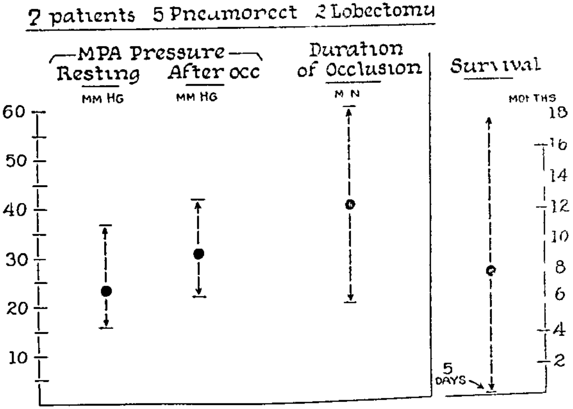


Fig 5—Results of pressure studies in 7 patients who had sustained increments in main pulmonary artery pressure following occlusion and who are now all dead following resectional therapy The average value and the extremes are shown The increment following occlusion in this group of patients averaged 8 mm Hg

The usual response to occlusion of the pulmonary artery to the right or left lung has been a transient increase of around 4 to 8 mm Hg in the main pulmonary artery, and a return to pre occlusion levels within ten to twenty minutes The importance of a resting elevation of the main pulmonary artery pressure and a sustained increment following occlusion was emphasized by Carlens and his associates[1, 3] and in our earlier report[9] The significance of these observations was recently further emphasized in the subsequent report by Bagger and his associates[4] In reporting on 109 patients carefully studied and followed for three to four years they found that in their entire series the mean resting pressure was between 18 and 19 mm Hg which they considered to lie within the upper limits of normal values They were able to divide their patients in the pulmonary capillary pressure, and since the pulmonary capillary pressure is generally held to be essentially the same as the pulmonary vein and left auricular pressure, then it becomes apparent that, even at rest preoperatively, this patient was having some degree of left heart strain.

Blood gas analyses distal to the occluding balloon in a lobar artery have revealed blood completely saturated with oxygen (Fig. 8). Actually, the distal sample invariably has had a higher oxygen content than the brachial artery and the pulmonary capillary sample. That this complete saturation is due to a long equilibration time between ventilated alveoli and stagnant capillary blood is indicated not only by the fact that the oxygen saturation exceeds that in the systemic circulation but also by the very low pCO_2. As Brofman states,[6, 7] presumably distal to occlusion retrograde flow and oxygenation of blood is taking place very rapidly. We feel that these studies supply further evidence that no precapillary anastomosis exists between the pulmonary and bronchial circulations and would appear to refute observations that bronchial artery flow, following pulmonary artery occlusion, increases as a result of a fall in pulmonary capillary pressure.

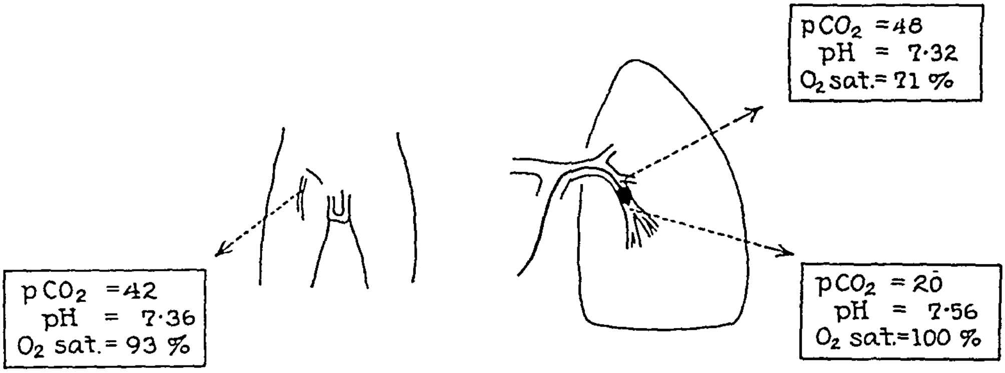


Fig. 8.—Analysis of the blood gases both proximal and distal to the occluding balloon which in this instance was placed in a lobar artery. The distal sample was taken five minutes after occlusion. Note that the oxygen saturation exceeds that in the femoral artery.

SUMMARY AND CONCLUSIONS

Unilateral pulmonary artery occlusion has now been carried out in almost 300 patients by various groups employing this method of study without mortality, nor any serious sequelae other than that reported by us. While it is a difficult and arduous study, and certainly not applicable for use as a routine method of investigation, it has proved to be very valuable in those borderline cases, particularly in patients with tuberculosis, where there is some question whether the patient's resection tolerance will be exceeded. While in our own studies we have been reluctant to withhold operation on the basis of positive findings in the study, it now seems clear from the collected experience that this would be justified and is even indicated, particularly in those patients not having malignant disease. Even in those having malignant disease, when the findings have been positive, an operation has had little to offer. In this latter situation such studies as these would, however, indicate the importance of doing a lobectomy rather than a pneumonectomy in carcinoma, provided it is feasible, when there is evidence that the resection tolerance of the patient would not be able to stand a pneumonectomy. The particular finding which has been universally obtained and which has indicated unequivocally a poor prognosis has been that of an elevation of the resting pulmonary artery pressure with a sustained increment following occlusion. Even if the resting pressure is not elevated, a sustained increment following occlusion has shown a poor prognosis.

A study of the pressures and the gas analyses distal to the occluding balloon has also yielded positive information with regard to the patient's ability to withstand pulmonary resection. In addition, this type of study has also indicated that there are no precapillary anastomoses between the pulmonary and systemic circulations. We feel that this method of study has great possibilities in the study of lung function, pulmonary vascular anatomy, and pulmonary embolism. The latter phase of this problem is under investigation by us and is being reported in detail elsewhere.

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OXYGEN AVAILABILITY TO THE BRAIN DURING INFLOW OCCLUSION OF THE HEART IN NORMOTHERMIA AND HYPOTHERMIA

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Many of the surgical techniques used in the therapy of intracardiac anomalies under direct vision depend on the application of either one or the other of two principles. These are: (a) the low flow rate or azygos principle based on the fact that the function of vital organs can be temporarily maintained on a cardiac output much reduced from normal,[1] and (b) the reduction of metabolism induced by hypothermia which lowers the oxygen requirements of the body thus permitting temporary occlusion of the circulation.[2] The application of either of these methods necessarily reduces the oxygen availability to vital organs. The purpose of this study is to determine the degree of change in oxygen availability to the brain during low flow rates and during hypothermia with temporary interruption of the circulation.

METHOD

The oxygen availability to the brain was measured by the polarographic technique which depends on the reduction of oxygen at a suitable cathode. If this cathode is maintained at about −0.6 volts with respect to a nonpolarizable anode, the current which flows, as oxygen is reduced, is proportional to the oxygen content of the tissue. Mongrel dogs weighing between 9 and 18 Kg. were prepared by the insertion of a platinum or gold cathode into the parietal lobe of the brain. The platinum electrodes consisted of 26-gauge platinum wire insulated in glass and having a 3 mm. exposed tip.[3] Gold cathodes were constructed from 26-gauge nylon insulated copper wire with an exposed tip of 5 mm. which was silver plated and then gold plated. These cathodes were left in situ for five to fifteen days before the experimental procedures to be described below were carried out. A silver chloride reference electrode placed subcutaneously was used as the anode. A variable shunt was used to compensate for variations in current flow from the cathode. The current flow resulting from the reduction of oxygen was continuously recorded with a direct writing suspension type photoelectric galvanometer.

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The animals were anesthetized with intravenous sodium pentobarbital (25 mg. per Kg.). The gas mixtures, described later, were given through a closed endotracheal system. Continuous records of brain oxygen availability were started soon after the induction of anesthesia and continued for the duration of the experiment. A thoracotomy was performed through the right fourth intercostal space and the superior and inferior venae cavae and the azygos vein were isolated. Temperatures were recorded from the rectum, right auricle, and brain. A thermistor[4] with a long lead was threaded through the femoral vein to the right auricle. Brain temperatures were obtained by inserting a thermistor mounted in a 20-gauge needle into the brain on the contralateral side to that of the cathode. The effects of low flow rate on the brain oxygen availability were then tested by occlusion of the inferior vena cava and superior vena cava cephalad to the azygos vein while the animal was being ventilated with 100 per cent oxygen. After a suitable recovery period, with total circulation intact, the animals were manually ventilated in sequence with 21, 10.27, and 4.91 per cent oxygen in nitrogen allowing a return of the brain polarographic record to a stable base line following the administration of each gas mixture. The carbon dioxide content of the above gas mixtures was less than 0.04 per cent.

A hypothermic state was then induced by extracorporeal cooling using the pump described by Clark and his associates.[5] The pump was filled with compatible donor blood containing 20 to 25 mg. heparin* per liter. The subject was given 1.0 mg. heparin per Kg. prior to extracorporeal circulation. Blood was obtained from one femoral artery and circulated through a stainless steel coil immersed in ice water. The cooled blood was returned to the arch of the aorta through a catheter inserted into the other femoral artery. By this method the brain temperature was reduced to about 28° C. in eleven to twenty-three minutes. The rate and degree of fall of temperature in the three sites measured was closely parallel. In the hypothermic state, oxygen availability to the brain was measured during complete circulatory occlusion and during the administration of the gas mixtures described above with an intact circulation. All animals were sacrificed after termination of the experiment.

RESULTS

The results of the above experimental procedures are presented graphically in Figs. 1-4. Oxygen availability to the cathode which reflects brain oxygen availability is expressed as a percentage change from control levels. In all the graphs the heavy interrupted line indicates the mean change in oxygen availability and the shaded area represents the range of variation. Fig. 1 shows the change in oxygen availability to the brain during low flow rates in normothermia in which the superior and inferior venae cavae were occluded temporarily with the azygos vein intact. It represents eight experiments carried out in 5 dogs. Within fifteen seconds after venous occlusion oxygen availability begins to change and is reduced to about 55 per cent of the control level at the end of one minute. Thereafter there is a more gradual fall to a relatively steady base line which represents a mean reduction of about 70 per cent in

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*The heparin in this project was kindly supplied by The Upjohn C

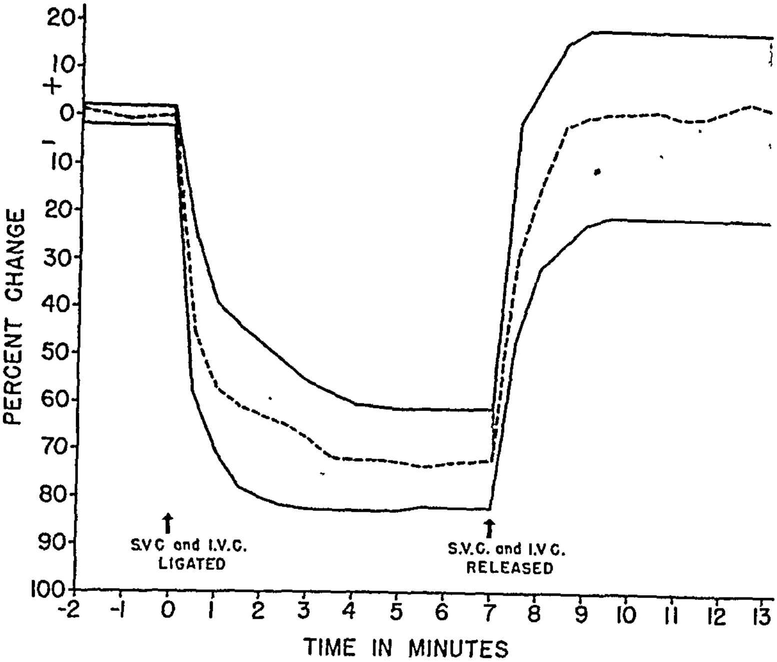

Fig. 1.—Per cent of change in oxygen availability to the brain in normothermia (azygos principle) during occlusion of the inferior and superior venae cavae with the azygos vein intact.

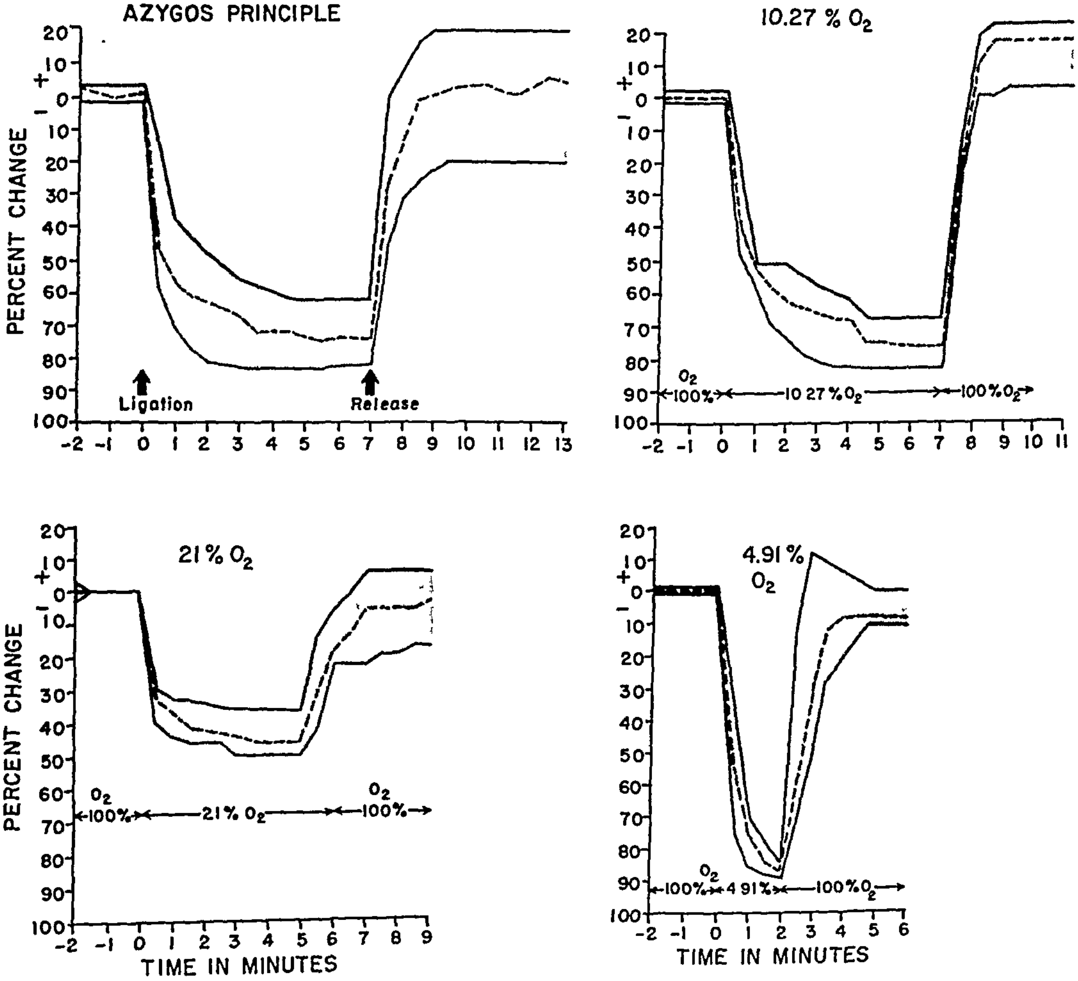

Fig. 2.—Comparison of changes in oxygen availability to the brain in normothermia during azygos flow and during ventilation with 21, 10.27, and 4.91 per cent oxygen in nitrogen.

oxygen availability. This level is reached in about four minutes. When normal venous return to the heart is re-established the events following venous occlusion are reversed with an abrupt and rapid rise followed by a slower gradual rise toward the control levels.

In an attempt to obtain an in vivo calibration of brain oxygen availability the normothermic animals were ventilated with gas mixtures containing varying amounts of oxygen. Fig. 2 indictates the percentage change in oxygen availability to the brain during the ventilation with gas mixtures containing 21, 10.27, and 4.91 per cent oxygen with an intact circulation. The similarity between the curves resulting from the breathing of 10.27 per cent oxygen and that resulting from low flow (azygos flow) is apparent. In both instances there is an immediate and rapid reduction in oxygen availability which stabilizes to a mean value of 70 per cent or less of the control reading within a period of about four minutes. The return toward control levels is immediate when the animals are allowed to breathe 100 per cent oxygen with the circulation intact.

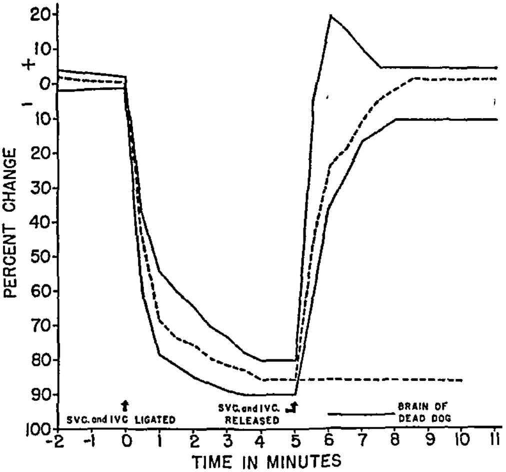

Fig. 3.—Per cent of change in oxygen availability to the brain in hypothermia during complete circulatory occlusion. Brain temperature, 26.5° to 29.5° C.

Fig. 3 shows the change in oxygen availability to the brain in hypothermia with complete inflow venous occlusion. This graph represents nine experiments in 5 dogs in which the brain temperature varied from 26.5° to 29.5° C. Immediately after total inflow occlusion there is a rapid fall in brain oxygen availability with a mean decrease of 86 per cent from the control level after a period of about four minutes. Occlusion of the aorta and pulmonary artery during venous occlusion did not significantly alter the reading. Stability of the reading, after the fall of oxygen availability is complete, is indicated by the continuation of the mean curve (Fig. 3) in which, in one inst occlusion was maintained for a period of ten minutes. Coincidentally, this reading fell on the mean. The return of oxygen availability toward control levels is rapid after restoration of the normal circulation. It is noteworthy that the reading obtained during hypothermia with circulatory occlusion is only 10 per cent higher than the base line obtained from the brain of the dead hypothermic animal (Fig. 3).

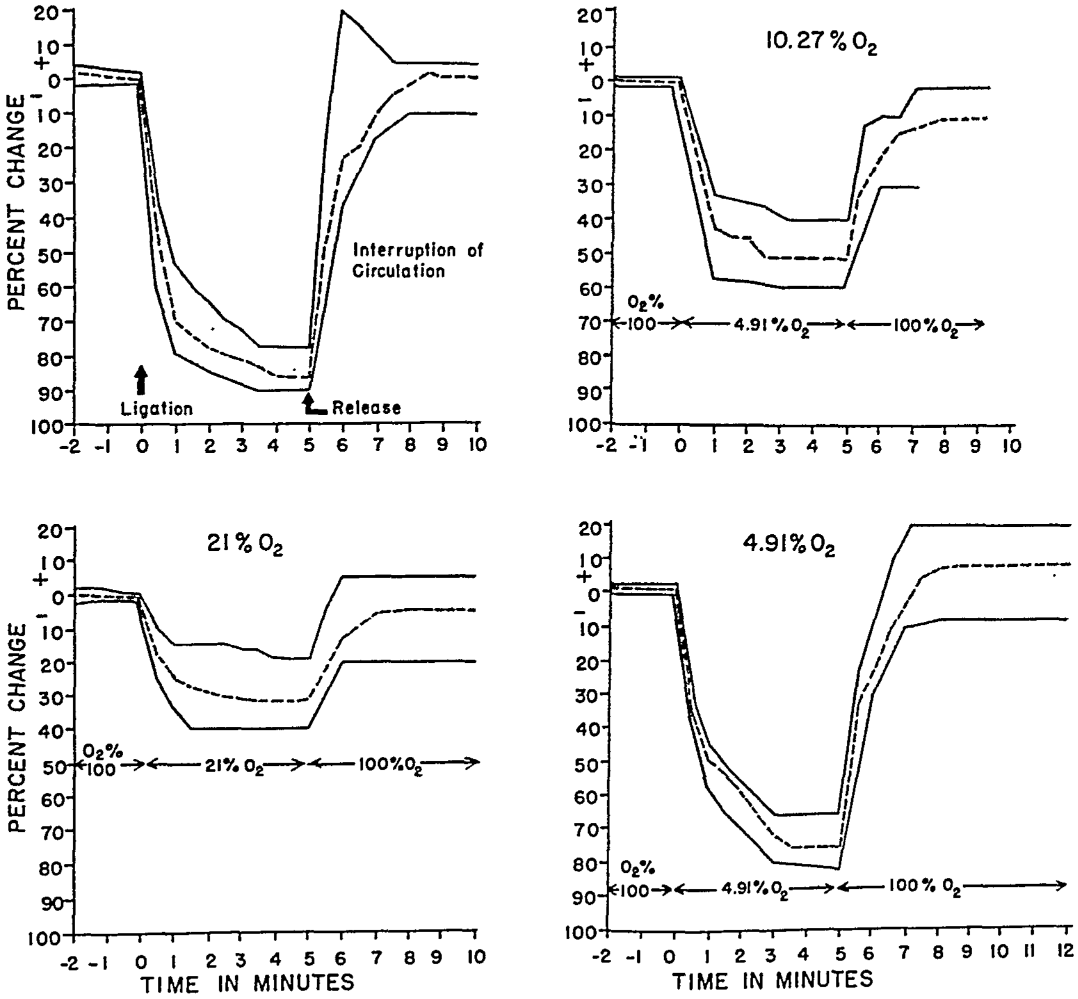

Fig. 4.—Comparison of changes in oxygen availability to the brain in hypothermia during complete circulatory occlusion and during ventilation with 21, 10.27, and 4.91 per cent oxygen in nitrogen. Brain temperature, 26.5° to 29.5° C.

Fig. 4 shows the change in oxygen availability to the brain in hypothermia during ventilation with 21, 10.27, and 4.91 per cent oxygen in nitrogen as compared with the reading obtained during circulatory occlusion in hypothermia. It is notable that the reading obtained during circulatory occlusion is somewhat lower than that obtained during the ventilation with 4.91 per cent oxygen. In both instances there is an immediate and rapid reduction of oxygen availability. The return toward control levels is immediate when the animals are allowed to breathe 100 per cent oxygen with the circulation intact.

DISCUSSION

The electrical output of the polarographic cathode is a function of the oxygen available in the immediate environment of its active tip. Thus, this cathode will measure oxygen brought to it both by free diffusion of the gas and by mechanical fluid transport. With such a cathode situated in the brain, *availability of oxygen to the cathode reflects local brain oxygen availability.*

The change in oxygen availability to the brain during temporary occlusion of the inferior vena cava and superior vena cava cephalad to the azygos have been described (see Fig. 1). It is noted that although there is uniformly an abrupt fall in oxygen availability to the brain after venous occlusion, the degree of fall and the return to control levels is variable. This variation could be explained on individual differences in the depth of anesthesia and the degree of reduction of the cardiac output. During occlusion of the inferior vena cava and superior vena cava cephalad to the azygos, the cardiac output depends primarily on the venous return through the azygos vein and the coronary venous system. Because these two fractions are variable, the cardiac output, although markedly reduced in all instances, is also variable.

Although the oxygen availability to the brain during low flow rates (azygos flow) and during ventilation with 10.27 per cent oxygen in normothermia are similar, it is appreciated that the dynamics of cerebral circulation are not comparable during the above two circumstances. In the former the brain is perfused with a low blood flow containing a high tension of oxygen, whereas in the latter, it is perfused with a high blood flow[6] at low oxygen tensions. Despite this variability in cerebral hemodynamics in the above two circumstances, these experiments indicate that the oxygen availability to the brain is nevertheless comparable.

A comparison of the changes in oxygen availability to the brain during the breathing of various gas mixtures in normothermia and hypothermia is of interest. In general, there was a larger and more rapid decrease in oxygen availability during the breathing of the same gas mixture in normothermia as compared to hypothermia. Also during the breathing of 4.91 per cent oxygen in normothermia, hyperventilation occurred after a period of about two minutes which necessitated the reinstitution of ventilation with 100 per cent oxygen. In hypothermia, the animals were ventilated for three to five minutes with 4.91 per cent oxygen without the appearance of hyperventilation. This clinical sign is interpreted to be the result of hypoxia. Since these experiments indicate that there is a marked reduction in brain oxygen availability in the hypothermic dog breathing 4.91 per cent oxygen although the clinical signs of hypoxia are not apparent, the possibility is raised that *hypothermia may mask the signs of hypoxia.*

It is noted in Fig. 3 that a small current flow is still detectable in the brain of the dead hypothermic animal. This may be due to minute amounts of polarographically active material, for example, iron or redox active substances.

In vitro experiments have shown that the current flow from a bare platinum cathode exposed to the same tension of oxygen in saline solution may be increased fivefold or more if the saline solution is agitated *(stirring eff[illegible]).* [illegible] is not known whether this effect occurs during the measurement of tissue oxygen availability. Experiments are in progress to compare the oxygen availability in the brain with cathodes described above and with cathodes unaffected by stirring with which quantitative determinations of tissue oxygen tension may be made. If a stirring effect occurs in tissues, one of the factors which would influence it would be the movement of blood and interstitial fluid in the environment of the cathode. A reduction of cerebral blood flow may conceivably result in an abrupt drop of oxygen availability while tissue oxygen tension falls at a slower rate. The relative importance in cerebral metabolism of brain oxygen availability as oppossed to brain oxygen tension warrants further investigation.

It is appreciated that brilliant results have been obtained by the use of low perfusion rates or hypothermia during the surgical therapy of intracardiac anomalies under direct vision. These experiments indicate that in either circumstance, oxygen availability to the brain is significantly reduced. It is possible that the protection afforded to the brain by hypothermia may not depend only on a decreased oxygen need. Furthermore, the reduction in oxygen availability in association with extremely low flow rates (azygos flow) may approach levels only slightly in excess of those resulting in brain hypoxia.

SUMMARY

A. Oxygen availability to the brain of dogs was measured polarographically during the following conditions: (a) temporary occlusion of the inferior vena cava and superior vena cava cephalad to the azygos vein (azygos principle), and (b) circulatory occlusion in hypothermia.

B. In normothermia, the oxygen availability to the brain drops precipitously after occlusion of the inferior and superior venae cavae with the azygos vein intact. It reaches an average level of 70 per cent below the control in a period of about three minutes.

C. The oxygen availability curve described in B is most closely reproduced by the breathing of 10.27 per cent oxygen.

D. In hypothermia with complete circulatory occlusion, the oxygen availability to the brain falls rapidly and precipitously to an average level of 86 per cent below the control.

E. The oxygen availability curve described in D is most closely reproduced by the breathing of less than 4.91 per cent oxygen.

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THE EFFECT OF SOMATOTROPHIN ON VENTRICULAR FIBRILLATION OF ARTERIOCLUSIVE AND HYPOTHERMIC ORIGIN

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VENTRICULAR fibrillation belongs to the most serious accidents which occur in the course of anesthesia or operation. If untreated and if irreversible, it leads shortly to death.

Bovine somatotrophin† was administered to a series of dogs prior to the attempted induction of ventricular fibrillation by right ventriculotomy under hypothermic conditions or by one stage coronary artery ligation in normothermic animals. Under control conditions such hearts fibrillate readily. However, those animals which had been premedicated were remarkably resistant to fibrillogenic stimuli. This experience leads us to believe that the mechanisms producing fibrillation may be modified on a metabolic level. The early local metabolic derangements produced by myocardial infarction are of special interest because of the production of ventricular fibrillation.

Bigelow[1] and his co-workers showed that the metabolic rate of dogs cooled to 20° C. *(rectal temperature) is about 15 per cent of metabolic rate of control* animals. Further studies by Bigelow[2] demonstrated that venous inflow occlusion could be undertaken for periods up to 15 minutes without demonstrable damage to the heart or central nervous system in those animals which survived the procedure; however, about one half of his animals died of ventricular fibrillation during the experiment.

Since that time an enormous number of experiments with intracardiac operations under hypothermia have been performed. During the past few years a growing number of operations on human subjects have also been carried out.

Senning[3] suggested that ventricular fibrillation might be used as an ideal state in which to operate at normal body temperature in connection with extracorporeal circulation. If the blood supply to the heart remains adequate, ventricular fibrillation is usually easy to reverse, both as regards experimental operations on animals and operations on man (Senning,[4] Helmsworth and his associates,[5] Glenn and Sewell[6]). Ventricular fibrillation has also been said to be equally useful with extracorporeal circulation as well as combined with hypo-

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†Supplied as "Riker 525" by the Riker Laboratories.

thermia (Juvenelle and co-workers,[7] Senning[8]). Ventricular fibrillation has also been recommended to facilitate intracardiac operations during hypothermia without combination with extracorporeal circulation; in this case, air embolism occurring in connection with the closure of the heart and resumption of the circulation is said to be prevented.

However, most surgeons have considered it advisable to avoid ventricular fibrillation if possible, without courting the hazards of electrical or chemical defibrillation. In studies regarding ventricular fibrillation, methods have been investigated to avoid this complication, and from them more definitive ideas regarding the nature, causes, and metabolic consequences have been discovered.

Montgomery and his co-workers,[9] while recognizing that it is currently impossible to characterize ventricular fibrillation at the cellular level, pointed to the increasing body of knowledge strongly implicating potassium maldistribution.

Not only is the occurrence of ventricular fibrillation in the hypothermic myocardium of direct practical concern to the surgeon, but the occurrence of *fibrillation in ischemic myocardium from any cause is becoming of increasing* surgical significance. Here again, potassium which is liberated from such ischemic muscle is the factor upon which definite evidence from a variety of experiments converge in unequivocal manner. If potassium is injected into a coronary artery of a dog with continuing circulation, it produces ectopic activity. Ischemic ventricular myocardium releases potassium in quantities sufficient to elevate the potassium concentration in the coronary venous blood from the ischemic area. Positive correlations can be demonstrated to exist between the periods of major elevation of potassium concentration in the muscle samples, and the periods of most intense ectopic ventricular activity. The potassium concentration in these samples decreases to approach the control levels at times which correspond approximately to the times when ectopic activity in the infarcted area disappears. The potassium content of infarcted muscle is greatly reduced at those times. Thus the evidence is overwhelming that locally liberated potassium is an excitatory agent for the remaining healthy myocardium (Harris[10]).

METHODS

Two groups of experiments are presented: those concerned with the effect of somatotrophin on ventricular fibrillation in hypothermia, and those concerned with the effect of somatotrophin on the fibrillation occurring consequent to ligation of a coronary artery.

The first group of experiments were carried out as follows. Mongrel dogs were placed in an ice-water bath after being deeply anesthetized with intravenous sodium pentobarbital (30 mg. per Kg.) to prevent shivering. Following tracheal intubation, the dog was hyperventilated with pure oxygen. When 29° C. rectal temperature was obtained, the dog was removed from the bath; a further drop of 3° to 6° C. of temperature occurred. Using aseptic technique, a right anterolateral thoracotomy incision was made through the fifth intercostal space. After entering the right thorax the azygos vein was ligated, pericardial sac opened widely, and both venae cavae were occluded.

In an initial series of experiments, the ascending aorta was occluded with a noncrushing clamp about 2.5 cm. distal to the coronary ostia. A control series of dogs received injections of saline solution. The experimental group was treated as follows: One hundred Choay units of somatotrophin (one Choay unit equals 0.205 Evans units) was administered by coronary perfusion. In an initial group of 5 dogs, no effect upon the onset of ventricular fibrillation could be demonstrated following right ventriculotomy.

In a second group of 5 experimental dogs, 100 units of somatotrophin were given intravenously immediately before occlusion of the venae cavae was carried out. This substance had no effect on the prevention of fibrillation following right ventriculotomy in this group.

The third experimental group received 100 units of somatotrophin 12 hours preoperatively and 100 units 4 hours preoperatively by intramuscular injections. Control animals received injections of saline solution. Following the institution of inflow stasis a 5 to 8 cm. incision was made in the right ventricle. After filling the heart with saline solution to prevent air embolism, the ventricular wall was sutured. The total occlusion time varied from 5 to 15 minutes, the average being 10 minutes.

Results. Right ventriculotomy is a fibrillogenic stimulus in the cold dog. Of 23 control dogs, all incurred fibrillation during ventriculotomy; many of these animals developed fibrillation with the initial stimulus. In those dogs to which somatotrophin was administered by coronary perfusion or to which it was given intravenously 5 minutes before the institution of vena caval occlusion, no protective effect against ventricular fibrillation was noted. Among the 32 dogs which had been premedicated with somatotrophin, 100 units given 12 hours and 4 hours preoperatively by intramuscular injection, 11 developed ventricular fibrillation. In 6 of the 11, attempts at defibrillation and resuscitation by electrical shock were successful.

TABLE I. SUMMARY OF DATA: HYPOTHERMIC DOGS
RIGHT VENTRICULOTOMY AS A FIBRILLATORY STIMULUS

	NUMBER DOGS	VENTRICULAR FIBRILLATION	RESUSCITATION
Control	23	23	0 of 23 attempts
Somatotrophin, 100 units I.V. 5 minutes prior to inflow occlusion	5	5	0 of 5 attempts
Somatotrophin, 100 units by coronary perfusion immediately following inflow occlusion	5	5	0 of 5 attempts
Premedication with somatotrophin, 100 units 12 hours and 4 hours, preoperatively	32	11	6 of 11 attempts

Similar experiments were carried out in experimental and control animals following ligations of coronary arteries.

Method.—Mongrel dogs were deeply anesthetized with intravenous sodium pentobarbital (30 mg. per Kg.). Following tracheal intubation, the dog was ventilated using the Phipps Bird respirator and room air. Under sterile conditions, an incision was made in the fourth left intercostal space, and the pericardium was opened. Three experiments were carried out. Either the trunk of the left coronary artery, or the left circumflex coronary artery and the left anterior descending coronary branches were ligated close to their origins, or the left circumflex coronary was ligated. An attempt was made to spare the septal branch of the left coronary artery in all experiments save where the main trunk of the left coronary artery was ligated.

Results: These are summarized in Table II. In all 3 groups, all test animals were given 100 units of somatotrophin 12 hours and 100 units 4 hours preoperatively by intramuscular injection. Control animals received saline injections. In some of the chronic studies, the animals were observed for 14 days and then sacrificed.

In Group I, the trunk of the left common coronary artery was ligated at its origin. In the control group of 3 animals, the average survival time was 3 minutes. In the treated group of 8 animals, the average survival time was 13 minutes.

TABLE II. SUMMARY OF DATA: CORONARY ARTERY LIGATIONS

	NUMBER OF DOGS	VENTRICULAR FIBRILLATION	RESUSCITATION	NUMBER SURVIVING/ TOTAL NUMBER		
				60 MIN.	24 HR.	14 DAYS
Occlusion of trunk of left common coronary artery						
Control	3	3 (survived 3 min.)				
Treated	8	8 (survived 13 min.)				
Occlusion of left anterior descending and left circumflex arteries						
Control	12	12	0 of 12 attempts	0	0	0
Treated	13	5	2 of 5 attempts	10/13	6/13	3/13
Occlusion of left circumflex artery						
Controls				15/28	10/28	6/17
Treated (50 u.)*				7/11	6/11	5/11
Treated (100 u.)				18/21	13/20	9/20
All treated				25/32	19/31	14/31

*These animals received 50 units of somatotrophin 12 hours and 4 hours, preoperatively.

In the second experimental group, the left anterior descending and the left circumflex coronary arteries were ligated close to their origins. It is seen that 12 out of 12 control animals showed ventricular fibrillation, and no attempts at resuscitation were successful. In the treated group of 13, on the other hand, only 5 exhibited immediate fibrillation and 2 of the 5 could be defibrillated by electrical shock. Since this procedure was found to be a rather severe one because of the marked hemodynamic changes incident to devascularization of the left ventricle, it was felt that a less severe test and one which would demonstrate the effects of somatotrophin on the fibrillatory threshold would be achieved by ligation of the left circumflex artery. In this third group, no attempts were made at defibrillation. Death during the first 24 hours can be attributed directly to fibrillation.

Protection by the hormone preparation was seen in all experiments When the results were subjected to statistical analysis, using survival at 30 minutes, 1 hour, 24 hours, and 14 days, protection was found to be highly significant ($p<0.001$)

DISCUSSION

The increased irritability of the ventricles in the hypothermic dog has been observed by several groups of investigators[1, 11, 12]

Swan and his co-workers[13] found that when dogs are cooled to a rectal temperature of 25° C with inflow occlusion to the heart, many animals incurred ventricular fibrillation, especially when the occlusion of the venae cavae was released The incidence of fibrillation was a function of ventilatory rate In the hypoventilated animals, it was 50 per cent, in the hyperventilated group, 8 per cent The only significant difference between these two groups was the blood pH In both groups, the plasma potassium was consistently low In the hypoventilated hypothermic dog, the renal excretion of potassium was several times greater than would be required to account for the loss of extracellular potassium, indicating a loss of intracellular potassium in the hypothermic animal with a low blood pH It was concluded that hyperventilation was a successful method for reducing the incidence of fibrillation in the cold animal

Another apparent relationship between fibrillation and potassium was demonstrated by Swan and his associates[13] They found that the fibrillating hypothermic heart could rarely be converted to normal rhythm by massage combined with electric shock However, with the method introduced in 1904 by D'Hallum[14] and studied by Hooker[15] according to which ventricular fibrillation is stopped with potassium chloride and regular contractions restored with calcium chloride both drugs being perfused into the coronary arteries, they found that the fibrillation could usually be converted to normal rhythm directly or by the use of electrical shock Frohlicher,[16] in 1945, introduced the use of acetylcholine for defibrillating a mammalian heart Fischer and Frohlicher,[17] in 1948, successfully used adenosine triphosphoric acid (ATP) Montgomery and associates[9] demonstrated that Prostigmin has a marked antifibrillatory effect upon the ventricular myocardium of the hypothermic dog The hypothermic myocardium during respiratory acidosis increases in potassium, while the opposite obtains during respiratory alkalosis, that is, potassium balance is maintained During fibrillation the hypothermic myocardium loses potassium

An experiment suggesting a relationship of potassium to fibrillation was carried out by Brown and Miller,[18] who found a high incidence of fibrillation in dogs suddenly changed from a breathing mixture containing a high concentration of carbon dioxide to room air Similar experiments were carried out by Young, Sealy, Harris, and Botwin[19] It was found that the serum potassium rose as the pH fell when the animals were being ventilated with 20 per cent carbon dioxide When the animals had been breathing this gas mixture for 2 to 4 hours, they were suddenly allowed to breathe room air This maneuver resulted in a rapid rise in pH, and the serum potassium at first rose suddenly to even higher levels before beginning to fall toward normal The animals incurred ventricular fibrillation during the time of the abrupt rise in serum potassium. The varied data summarized here suggest a relationship between the distribution of intra- and extracellular potassium and ventricular fibrillation. Somatotrophin has been demonstrated to be myoglycostatic; since the deposition and maintenance of glycogen stores entails stoichiometric quantities of potassium, such an agent might be important in maintaining a normal intracellular potassium balance. Such a function has been reported in the experimental hypothermic animal by Laborit and his co-workers.[20]

The results reported here show that premedication with somatotrophin of the hypothermic dog has a pronounced antifibrillatory effect. Further, in those instances in which fibrillation occurred, reversal of the fibrillation to a normal mechanism was accomplished in over one half of the attempts. This is in marked contrast to the ineffectiveness of resuscitation in the control animals. The fact that the incidence of ventricular fibrillation in hypothermia is significantly influenced by the anesthetic agent employed was demonstrated by Covino, Charleson, and D'Amato.[21] However, in our studies the same anesthetic agent was used throughout in comparable dosage.

Montgomery and associates[9] postulated that Adrenalin and sympathetic impulses to the heart might induce or potentiate ventricular fibrillation. Cahn and Melon,[22] in October, 1954, reported the use of Xylocaine blockade of the sinoauricular node to prevent ventricular fibrillation in dogs during hypothermia. Riberi, Siderys, and Shumacker[23] have recently reported on the effectiveness of this maneuver utilizing procaine. Shumacker and his associates[24] have shown that bilateral sympathetic denervation of the heart in hypothermic animals prevented fibrillation in all animals. Thus, interruption of nervous, precipitating factors may be as effective as measures directed to the metabolic level of the myocardium. Other techniques of accomplishing defibrillation have been well known for some time (Burmeister[25, 26]).

Ventricular ectopic activity following abrupt ligation of a coronary artery occurs in three phases (Harris,[27, 28] Beck[29]). The first phase has a duration of about 10 minutes. During this period ectopic activity develops in almost all animals and precipitates ventricular fibrillation in 30 per cent to 50 per cent of them. In the animals in which ventricular fibrillation does not develop, ectopic activity passes through a maximum and declines to reach a level of only an occasional premature beat or ceases completely within 20 minutes or less after occlusion. Throughout these experiments all ligations were performed in one stage to avoid the two-stage phenomena.

The second phase in the pattern of ectopic foci is a period of little or no ectopic activity following the first phase, or following a two-stage occlusion by-pass of the first stage. This period, during which there are only occasional ectopic activities, may have a duration of 4.5 to 8 hours, the average being 5 to 6 hours. With the introduction of the third phase there is a significant increase in the frequency of ectopic beats. The frequency of ectopic beats increases rapidly for the succeeding 4 hours, and then more slowly. Ventricular tachycardia of high frequency thus is produced and may obtain for 2 to 4 days. Necrosis of the myocardium begins simultaneously with the beginning of the third phase. The ligation of the left circumflex coronary artery was felt to provide an adequate metabolic situation to induce fibrillation without inviting the more severe hemodynamic consequences of occlusion of the entire left coronary artery.

It is significant that the greatest degree of protection is seen in the periods of from 60 minutes to 24 hours following the ligation of the coronary vessels. This would appear to be explained by the metabolic events following the onset of myocardial necrosis.

In the protective action in hypothermic dogs and in dogs following ligations of coronary vessels, *a certain latent period is necessary before any protection* is achieved. The protective action apparently endures in the ligation experiments for at least 24 hours.

The mechanism of action of somatotrophin in producing these effects is unknown. It has been shown that the protein content in the bodies of hypophysectomized rats increases when the animals have received treatment with growth hormone (Li[30]). Growth hormone is a powerful protein anabolic agent as demonstrated by experiments with sulfur-35-labeled albumin, in which the effect of growth hormone on the metabolism of plasma albumin was studied. It was found that growth hormone administered to the adult hypophysectomized rat produces an acceleration of albumin synthesis, increasing it by a factor of two or more (Ulrich[31]). Certain it is that intracellular potassium increases with protein deposition, and the rate of potassium mobility across cellular membranes may vary with intracellular protein. It may be that cardiac muscle, as Gerard[32] has shown for the central nervous system, does not depend on sugar and high-energy phosphate esters for quick energy release, but rather depends upon the breakdown of lipo- and nucleoprotein.

SUMMARY

1. In a significant number of cases premedication with somatotrophin prevents the ventricular fibrillation which regularly follows right ventriculotomy in the hypothermic dog.

2. In a series of dogs submitted to various types of coronary artery ligations, premedication with somatotrophin produced protection in all experiments to a highly significant degree ($p<0.001$).

3. Both in the hypothermic dogs and in those subjected to coronary artery *ligations, a latent period is required before any protective effect may be* demonstrated.

4. The mechanism of action of somatotrophin is unknown. All evidence points to activity on a cellular metabolic level.

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incurred ventricular fibrillation during the time of the abrupt rise in serum potassium. The varied data summarized here suggest a relationship between the distribution of *intra- and extracellular potassium and ventricular fibrillation.* Somatotrophin has been demonstrated to be myoglycostatic; since the deposition and maintenance of glycogen stores entails stoichiometric quantities of potassium, such an agent might be important in maintaining a normal intracellular potassium balance. Such a function has been reported in the experimental hypothermic animal by Laborit and his co-workers.[20]

The results reported here show that premedication with somatotrophin of the hypothermic dog has a pronounced antifibrillatory effect. Further, in those instances in which fibrillation occurred, reversal of the fibrillation to a normal mechanism was accomplished in over one half of the attempts. This is in marked contrast to the ineffectiveness of resuscitation in the control animals. The fact that the incidence of ventricular fibrillation in hypothermia is significantly influenced by the anesthetic agent employed was demonstrated by Covino, Charleson, and D'Amato.[21] However, in our studies the same anesthetic agent was used throughout in comparable dosage.

Montgomery and associates[9] postulated that Adrenalin and sympathetic impulses to the heart might induce or potentiate ventricular fibrillation. Cahn and Melon,[22] in October, 1954, reported the use of Xylocaine blockade of the sinoauricular node to prevent ventricular fibrillation in dogs during hypothermia. Riberi, Siderys, and Shumacker[23] have recently reported on the effectiveness of this maneuver utilizing procaine. Shumacker and his associates[24] have shown that bilateral sympathetic denervation of the heart in hypothermic animals prevented fibrillation in all animals. Thus, interruption of nervous, precipitating factors may be as effective as measures directed to the metabolic level of the myocardium. Other techniques of accomplishing defibrillation have been well known for some time (Burmeister[25, 26]).

Ventricular ectopic activity following abrupt ligation of a coronary artery occurs in three phases (Harris,[27, 28] Beck[29]). The first phase has a duration of about 10 minutes. During this period ectopic activity develops in almost all animals and precipitates ventricular fibrillation in 30 per cent to 50 per cent of them. In the animals in which ventricular fibrillation does not develop, ectopic activity passes through a maximum and declines to reach a level of only an occasional premature beat or ceases completely within 20 minutes or less after occlusion. Throughout these experiments all ligations were performed in one stage to avoid the two-stage phenomena.

The second phase in the pattern of ectopic foci is a period of little or no ectopic activity following the first phase, or following a two-stage occlusion by-pass of the first stage. This period, during which there are only occasional ectopic activities, may have a duration of 4.5 to 8 hours, the average being 5 to 6 hours. With the introduction of the third phase there is a significant increase in the frequency of ectopic beats. The frequency of ectopic beats increases rapidly for the succeeding 4 hours, and then more slowly. Ventricular tachycardia of high frequency thus is produced and may obtain for 2 to 4 days. Necrosis of the myocardium begins simultaneously with the beginning of the third phase. The ligation of the left circumflex coronary artery was felt to provide an adequate metabolic situation to induce fibrillation without inviting the more severe hemodynamic consequences of occlusion of the entire left coronary artery

It is significant that the greatest degree of protection is seen in the periods of from 60 minutes to 24 hours following the ligation of the coronary vessels This would appear to be explained by the metabolic events following the onset of myocardial necrosis

In the protective action in hypothermic dogs and in dogs following ligations of coronary vessels, a certain latent period is necessary before any protection is achieved The protective action apparently endures in the ligation experiments for at least 24 hours

The mechanism of action of somatotrophin in producing these effects is unknown It has been shown that the protein content in the bodies of hypophysectomized rats increases when the animals have received treatment with growth hormone (Li[30]) Growth hormone is a powerful protein anabolic agent as demonstrated by experiments with sulfur 35 labeled albumin, in which the effect of growth hormone on the metabolism of plasma albumin was studied It was found that growth hormone administered to the adult hypophysectomized rat produces an acceleration of albumin synthesis, increasing it by a factor of two or more (Ulrich[31]) Certain it is that intracellular potassium increases with protein deposition, and the rate of potassium mobility across cellular membranes may vary with intracellular protein It may be that cardiac muscle, as Gerard[32] has shown for the central nervous system, does not depend on sugar and high energy phosphate esters for quick energy release, but rather depends upon the breakdown of lipo and nucleoprotein

SUMMARY

1 In a significant number of cases premedication with somatotrophin prevents the ventricular fibrillation which regularly follows right ventriculotomy in the hypothermic dog

2 In a series of dogs submitted to various types of coronary artery ligations premedication with somatotrophin produced protection in all experiments to a highly significant degree ($p<0.001$)

3 Both in the hypothermic dogs and in those subjected to coronary artery ligations, a latent period is required before any protective effect may be demonstrated

4 The mechanism of action of somatotrophin is unknown All evidence points to activity on a cellular metabolic level

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TOTAL BODY PERFUSION FOR OPEN CARDIOTOMY UTILIZING THE BUBBLE OXYGENATOR

Physiologic Responses in Man

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SINCE May, 1955, a simple disposable bubble[1, 2] oxygenator has been utilized together with a pump in 80 patients to permit intracardiac reparative surgery under direct vision by totally by-passing the heart and lungs. These patients have ranged in age from 4 weeks to 38 years and in weight from 2.6 Kg. to 56 Kg. A variety of thirteen types of congenital malformations or acquired cardiac lesions were found in these patients. The detailed considerations pertaining to these corrective procedures are the subject of other reports. Herein, it is our intention to present an analysis of the physiologic responses in the first 60 of these patients to their interval of total cardiopulmonary by-pass at various perfusion rates including observations upon acid base alterations, oxygen consumption rates, effects upon the clotting mechanism, hemolysis, and arterial pressures.

Previous experience has indicated the usefulness of perfusions at flow rates considerably less than the full cardiac output[3, 4] and in general this concept has been the basis for these procedures. Moreover, since the pump oxygenator utilized in these operations has the capacity to provide any desired perfusion rate within the physiologic range, and inasmuch as an optimum perfusion rate for human beings is not known, these patients were perfused by intention at rates of flow varying from 26 to 60 c.c. per Kg. of body weight per minute to gain more objective data on this important consideration. The arterial perfusion rate selected for any given patient was maintained throughout the entire procedure, independent of occasional fluctuations of the venous return, by addition of blood to the extracorporeal circuit as needed. Consequently, the responses of the patients to a constant volume perfusion could be studied in relationship to that flow rate.

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As total body perfusions often have been characterized by the development of blood acid-base alterations, our attention was directed particularly toward determining what factors contribute to these variations.

METHODS

One hundred per cent oxygen was used in the oxygenator to arterialize the venous blood, and the carbon dioxide was allowed to escape freely from the blood on the theory that a respiratory alkalosis would tend to counterbalance to some extent any tendency toward the development of a metabolic acidosis. The patient's control blood samples were drawn just before the perfusion after a period of controlled respiration with the chest open.

The biochemical data obtained have been grouped according to perfusion rates in order to define, if possible, an optimum flow rate, and also have been grouped according to whether cyanotic or acyanotic heart disease was present because of the substantial differences existing preoperatively in these two conditions.

To facilitate a comparison between perfusion rates and the development of acid-base alterations, plasma bicarbonate concentrations (alkaline reserve) have been determined. Values for pH alone are unreliable for a precise evaluation as the acid-base balance may vary widely without direct reflections on the pH due to compensation by the blood buffers. The differences in bicarbonate concentrations between the control values and test samples represent a quantitative determination of the alterations in the acid-base balance. To compare accurately these bicarbonate concentrations, the measured values for each patient need to be converted by calculation to a standard point of reference, a pH of 7.4 in these studies. The formula of Peters and Van Slyke[*][7] was used for this calculation.

RESULTS

Acid-Base Changes During Total Body Perfusion.—

1. *In patients with acyanotic heart disease:* Table I illustrates the acid-base response to total body perfusion in 45 acyanotic patients studied. Control blood samples were not taken from the infants or small children; therefore complete determinations of the blood chemistry in the pre-perfusion state were available on only 10 patients. One may note from these data that all patients began the perfusion in a state of respiratory alkalosis as manifested by the elevated pH and depressed total CO_2 values. The final blood pH values measured at the conclusion of the perfusion interval were in the normal or near normal range for all of the perfusion rates studied. (Table I.) However, the differences between the control arterial bicarbonate levels calculated at pH 7.4, and the corresponding values at the termination of the by-pass indicate a

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[*] $[HCO_3^-]\ pH\ 7.4 = [HCO_3^-]\ pH_x - [(7.4 - pH_x)\ (8.2 + 2.3\ Hgb.)]$

Where:

$[HCO_3^-]$ pH 7.4 = Plasma bicarbonate in mM/L. the sample at pH 7.4.
pH_x = Patient's measured hydrogen-ion concentration.
$[HCO_3^-]\ pH_x$ = Plasma bicarbonate at pH_x obtained from nomogram from patient's known pH_x and total CO_2 content or calculated from Henderson-Hesselbalch equation.
(8.2 + 2.3 Hgb.) = The slope of the buffer curve of whole blood with hemoglobin expressed as millimoles per liter which is $\frac{\text{Hgb. in Gms. \%}}{1.67}$

TABLE I. ACID-BASE RESPONSE TO TOTAL BODY PERFUSION IN PATIENTS WITH ACYANOTIC HEART DISEASE
(MEAN VALUES)

PERFUSION RATE C.C./KG./MIN.		NUMBER OF PATIENTS	MEAN DURATION OF BY-PASS (MIN.)
Group A	30-35	23	17½
Group B	36-41	10	16
Group C	50-60	12	11½

	ARTERY					VEIN		
	pH	TOTAL CO$_2$† mM/L	O$_2$ SATURATION (%)	PLASMA BICARBONATE‡ AT pH 7.4	HEMOGLOBIN (GM. %)	pH	TOTAL CO$_2$§ mM/L	PLASMA BICARBONATE AT pH 7.4
Group A								
Control*	7.50	20.7	95	22.7	13.9	7.41	22.9	22.1
Defect corrected	7.33	17.7	95	14.7	14.7	7.24	22.9	16.8
By-pass concluded	7.34	17.4	95	15.6	14.8	7.24	20.7	14.8
15 min. after by-pass	7.36	18.2	95	16.1	14.8	--		--
Group B								
Control*	7.50	20.7	95	22.7	13.9	7.41	22.9	23.2
Defect corrected	-	--	--		14.9	7.29	24.0	19.2
By-pass concluded	7.34	18.5	96	15.8	14.9	7.29	21.6	16.9
15 min. after by-pass	7.34	19.3		16.6	14.9	-	-	--
Group C								
Control*	7.50	20.7	95	22.7	13.9	7.41	22.9	22.1
Defect corrected	-	-	-		15.0	7.30	22.8	19.6
By-pass concluded	7.45	15.8	96	16.5	15.0	7.32	21.4	17.8
15 min. after by-pass	7.39	18.9		17.7	15.0		-	

*Samples taken just prior to by-pass.
†Normal value = 20-22.6 mM per liter.[30]
‡See text for method of calculation.
§Normal value = 22.7-25.9 mM per liter.[30]

fall in the bicarbonate concentration for all three perfusion rates. The mean decrease in blood bicarbonate concentration was for Group A (30 to 35 c.c. per Kg. per min.), 6.6 mM per liter, for Group B (36 to 41 c.c. per Kg. per min.), 6.1 mM per liter, and for Group C (50 to 60 c.c. per Kg. per min.), 5.5 mM per liter.

Table II illustrates the duration of these perfusions. As one might anticipate that longer time intervals of perfusion would increase the bicarbonate depression, the change of bicarbonate concentration for each patient was plotted on a scattergram (Fig. 1) in relation to total duration of his perfusion. Fig. 1 indicates that the changes of bicarbonate concentration are widely variable, but suggests that Group C patients had less of a change than did the other groups. However, to assess this apparent difference more accurately, these patients need to be compared in relationship to the duration of

TABLE II. CLASSIFICATION OF PERTINENT DATA RELATING TO THE PERFUSIONS IN THE 60 PATIENTS STUDIED

PATIENT GROUP	TYPE OF HEART DISEASE	NUMBER PATIENTS	RANGE OF PERFUSIONS (C.C./KG./MIN.)	MEAN VALUES: PERFUSION FLOW RATE (C.C./KG./MIN.)	TIME OF CARDIAC DEFECT CORRECTION	TOTAL PERFUSION TIME
A	Acyanotic	23	30-35	31.5	9' 30"	17' 30"
B	Acyanotic	10	36-41	37.5	11'	16' 0"
C	Acyanotic	12	50-60	52.5	8'	11' 30"
D	Cyanotic	11	26-35	30.0	10' 45"	25' 3"
E	Cyanotic	4	40-50	45.0	13' 45"	[illegible]

their respective perfusions; therefore only those perfusions in Group A and Group B which lasted no longer than the perfusion of Group C were compared statistically to determine if there was any significant difference in the bicarbonate depression in these three groups. The differences observed in these three (flow rate) groups under this condition of comparable perfusion times were not significant; therefore one is unable to correlate significant changes in blood bicarbonate with these three different perfusion rates.

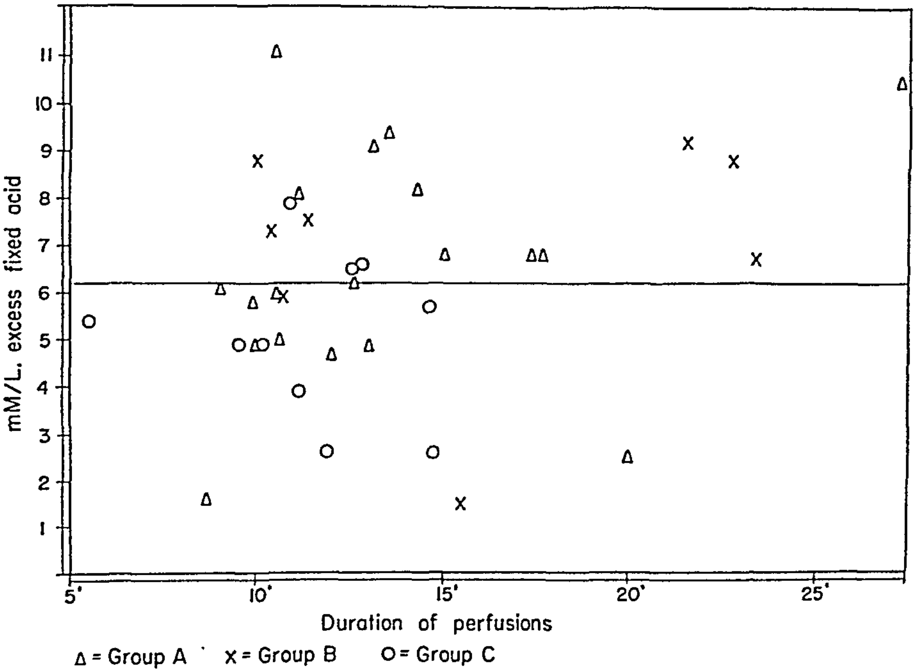


Fig. 1.—Relationship of plasma bicarbonate depression (accumulation of fixed acids) and duration of perfusion. (The solid line indicates the mean change.)

The patient's arterial samples taken about fifteen minutes after the termination of the perfusion indicate that the body mechanisms already had recovered as much as one mM per liter bicarbonate from their lowest levels toward their normal levels of 20 to 22.6 mM per liter (Table I).

2. *In patients with cyanotic heart disease:* In Table III is portrayed the acid-base balance of a group of patients with cyanotic heart disease sampled on the wards under ambulatory conditions without anesthesia and prior to corrective surgery. It may be noted from these data that all of the patients studied had reduced plasma bicarbonate levels. Moreover, in a number of these patients the fact that the arterial pH values were below normal levels indicates the existence of an uncompensated metabolic acidosis. Noteworthy, are the borderline and frankly elevated lactic acid values in these patients sampled under resting conditions.

The patients with cyanotic heart disease, as Table IV depicts, also developed a depression of their total bicarbonate during their perfusions, but the change from their control values was less than observed in the patients of Groups A, B, and C with acyanotic types of heart disease. In these cyanotic patients, their blood pH values were not significantly altered by the total bypass interval.

Lactic Acid Determinations.—Lactic acid determinations as a measure of fixed acids were made on a representative number of patients in each group. In each group, the lactic acid values at the conclusion of the by-pass averaged approximately two to three times the control value. The average final value for the acyanotic patients was 40 mg. per cent and for the cyanotic patients was 70 mg.

TABLE III. ALKALINE DEFICIT OF THE BLOOD OF PATIENTS WITH CONGENITAL CYANOTIC HEART DISEASE (PREOPERATIVE DATA)

	HEMOGLOBIN (GM. %)	ARTERIAL*			VENOUS*	
		pH_x	TOTAL CO_2 (mM/L.)	HCO_3^-§ AT pH 7.4	LACTIC‡ ACID (MG. %)	PLASMA CO_2 COMB. POWER IN MEQ./L.
J. O.†	11.6	7.32	22.7	19.6	104	24
S. S.	13.2	7.44	16.2	16.7	--	24
D. W.	13.1	7.40	18.4	18.4	20	21
M. W.	15.1	7.28	19.1	14 5	--	15
M. E.	17.3	7.44	21.9	22.3	12	16
C. S.	17.4	7.27	17.4	12.2	--	22
P. L.	16.9	7.33	15.6	12.6	--	18
E. B.	23.0	7.20	15.7	6 5	19	21
D. C.	24.0	7.43	14.0	15.2	20	22
J. A.	22.5	7.36	17.8	15.2	23	23
Mean values	17.4	7.35	17.9	15.3	33	20.6

*Blood samples drawn from ward patients without anesthesia under ambient conditions.

†Complete transposition of the great vessels, all others were patients with tetralogy of Fallot.

‡Normal value = 5 to 20 mg. per cent.

§Normal value = 20-22.6 mM per liter.

TABLE IV. ACID-BASE RESPONSE TO TOTAL BODY PERFUSION IN PATIENTS WITH CYANOTIC HEART DISEASE

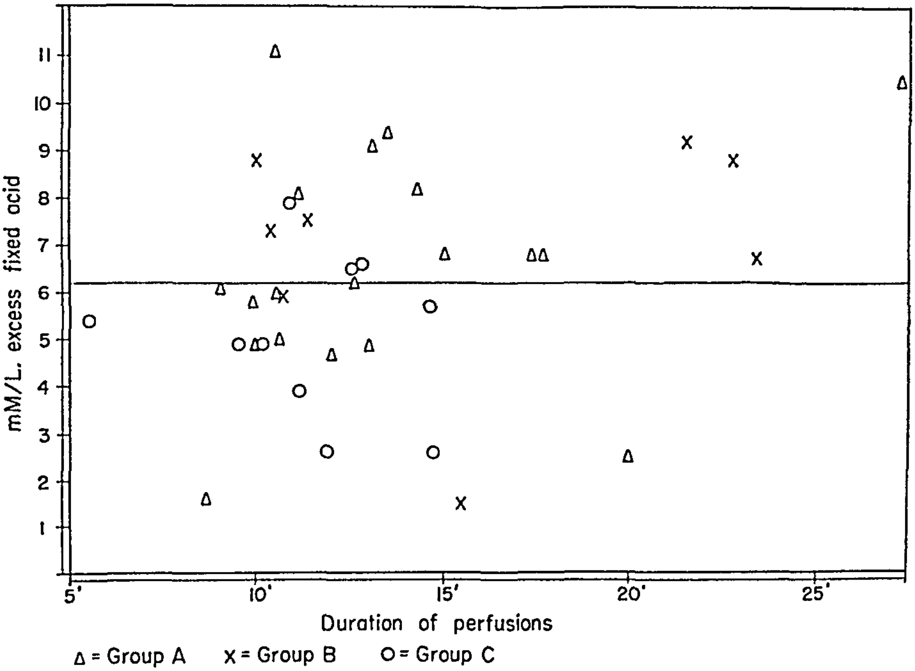
PERFUSION RATE C.C./KG./MIN.	NUMBER OF PATIENTS	MEAN DURATION OF BY-PASS (MIN.)
Group D: 25-35	11	25.5
Group E: 40-50	4	17.5

	ARTERY			VEIN			
	pH	TOTAL CO_2 (mM/L.)	PLASMA BICARBONATE AT pH 7.4 IN mM/L.	HEMOGLOBIN (GM. %)	pH	TOTAL CO_2 (mM/L.)	PLASMA BICARBONATE AT pH 7.4 IN mM/L.
Group D							
*Control	7.35	17.9	15.2	14.9	7.37	20.6	18.6
Defect corrected	--	--	--	14.7	7.22	24.2	19.3
By-pass concluded	7.36	14.7	11.9	15.7	7.23	18.8	12.4
15 min. after by-pass	7.38	16.0	14.6	15.1	--	--	--
Group E							
Defect corrected	--	--	--	15.4	7.26	21.4	16.0
By-pass concluded	7.35	14.2	12.4	15.4	7.26	19.2	13.9
15 min. after by-pass	7.28	15.3	11.0	15.4	--	--	--

*Represents controls for both Groups D and E.

per cent. The cyanotic patients began their perfusions with considerably elevated blood levels of lactic acid in some instances as Table III indicates. These values may be compared with normal values of 5 to 20 mg. per cent and values of 100 mg. per cent observed in athletes after competition such as a basketball game.

their respective perfusions; therefore only those perfusions in Group A and Group B which lasted no longer than the perfusion of Group C were compared statistically to determine if there was any significant difference in the bicarbonate depression in these three groups. The differences observed in these three (flow rate) groups under this condition of comparable perfusion times were not significant; therefore one is unable to correlate significant changes in blood bicarbonate with these three different perfusion rates.



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The patients with cyanotic heart disease, as Table IV depicts, also developed a depression of their total bicarbonate during their perfusions, but the change from their control values was less than observed in the patients of Groups A, B, and C with acyanotic types of heart disease. In these cyanotic patients, their blood pH values were not significantly altered by the total bypass interval.

Lactic Acid Determinations—Lactic acid determinations as a measure of fixed acids were made on a representative number of patients in each group In each group, the lactic acid values at the conclusion of the by pass averaged approximately two to three times the control value The average final value for the acyanotic patients was 40 mg per cent and for the cyanotic patients was 70 mg per cent The cyanotic patients began their perfusions with considerably elevated blood levels of lactic acid in some instances as Table III indicates These values may be compared with normal values of 5 to 20 mg per cent and values of 100 mg per cent observed in athletes after competition such as a basketball game

TABLE III ALKALINE DEFICIT OF THE BLOOD OF PATIENTS WITH CONGENITAL CYANOTIC HEART DISEASE (PREOPERATIVE DATA)

	HEMOGLOBIN (GM %)	ARTERIAL*			VENOUS*	
		pH_x	TOTAL CO (mM/L)	HCO_3§ AT pH 7 4	LACTIC‡ ACID (MG %)	PLASMA CO COMB POWER IN MEQ/L
J O †	11 6	7 32	22 7	19 6	104	24
S S	13 2	7 44	16 2	16 7		24
D W	13 1	7 40	18 4	18 4	20	21
M W	15 1	7 28	19 1	14 5	--	15
M E	17 3	7 44	21 9	22 3	12	16
C S	17 4	7 27	17 4	12 2	-	22
P L	16 9	7 33	15 6	12 6		18
E B	23 0	7 20	15 7	6 5	19	21
D C	24 0	7 43	14 0	15 2	20	22
J A	22 5	7 36	17 8	15 2	23	23
Mean values	17 4	7 35	17 9	15 3	33	20 6

*Blood samples drawn from ward patients without anesthesia under ambient conditions
†Complete transposition of the great vessels all others were patients with tetralogy of Fallot
‡Normal value = 5 to 20 mg per cent
§Normal value = 20 22 6 mM per liter

TABLE IV ACID BASE RESPONSE TO TOTAL BODY PERFUSION IN PATIENTS WITH CYANOTIC HEART DISEASE

PERFUSION RATE C C /KG /MIN		NUMBER OF PATIENTS	[illegible] OF BY PASS MI[illegible]
Group D	25 35	11	
Group E	40 50	4	[illegible]

	ARTERY			VEIN			
	pH	TOTAL CO_2 (mM/L)	PLASMA BICARBONATE AT pH 7 4 IN mM/L	HEMOGLOBIN (GM %)	pH	TOTAL CO (mM/L)	PLASMA BICARBONATE AT pH 7 4 IN mM/L
Group D							
*Control	7 35	17 9	15 2	14 9	7 37	20 6	18 6
Defect corrected	- -	-		14 7	7 22	24 2	19 3
By pass concluded	7 36	14 7	11 9	15 7	7 23	18 8	12 4
15 min after by pass	7 38	16 0	14 6	15 1			- -
Group E							
Defect corrected			-	15 4	7 26	21 4	16 0
By pass concluded	7 35	14 2	12 4	15 4	7 26	19 2	[illegible]
15 min after by pass	7 28	15 3	11 0	15 4		- -	

*Represents controls for both Groups D and E

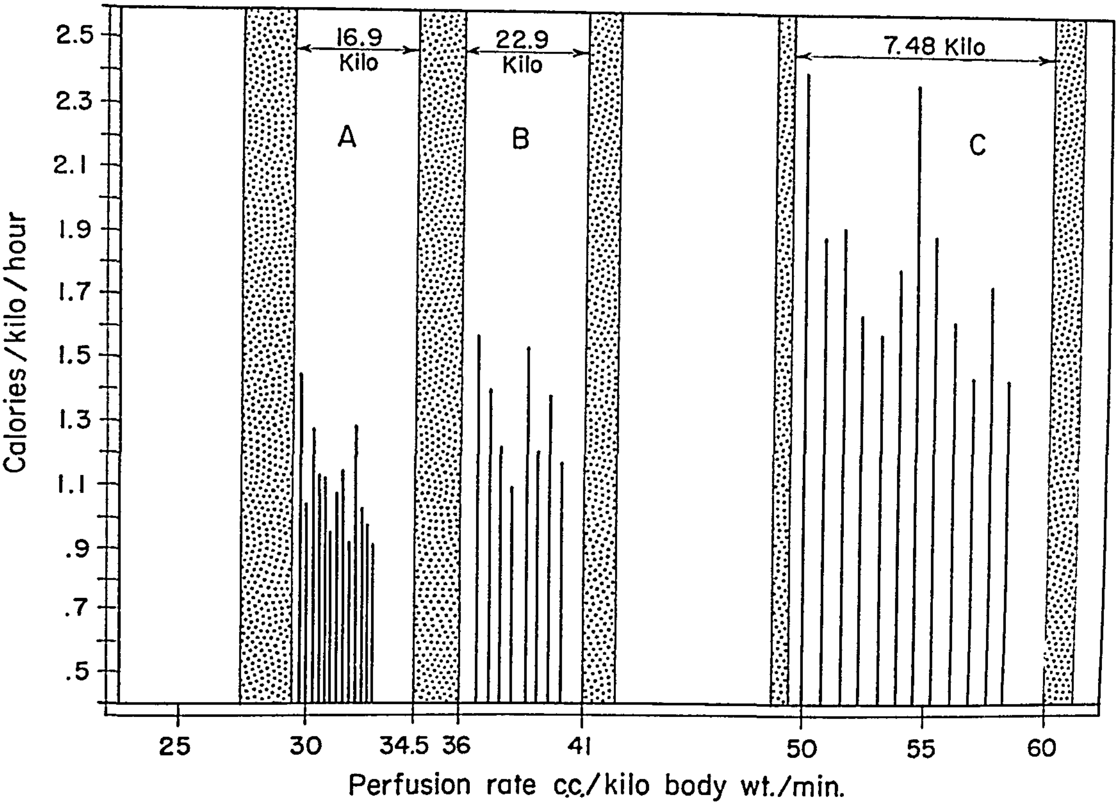

Fig. 2.—Oxygen consumption rates during total body perfusion in patients with acyanotic heart disease. Mean body weights for each group are indicated.

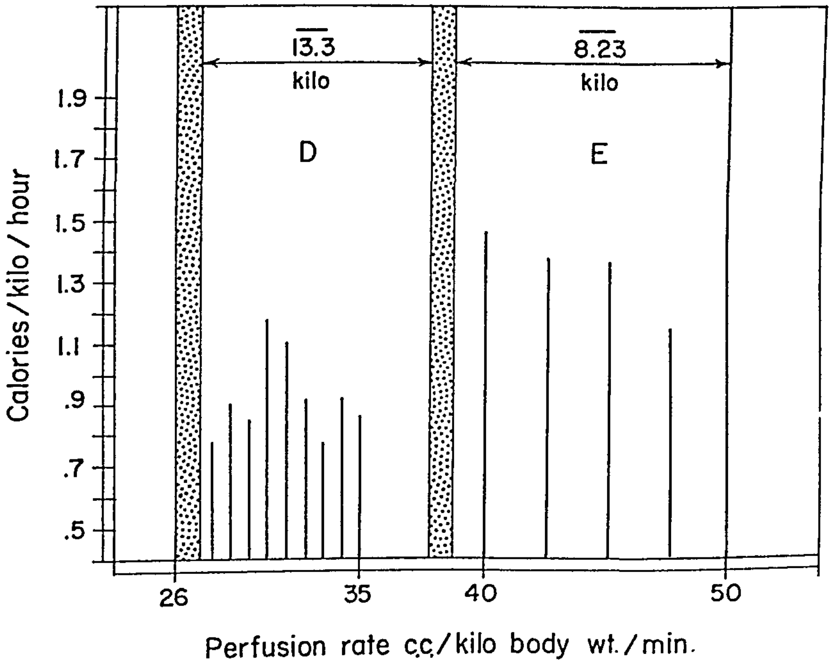

Fig. 3.—Oxygen consumption rates during total body perfusion in patients with cyanotic heart disease. Mean body weights for each group are indicated.

Oxygen Consumption Rates.—Oxygen consumption rates during the by-pass interval were calculated for each group of patients. These values as calories used per kilogram of body weight per hour, are summarized in Fig. 2 for the acyanotic patients and in Fig. 3 for the cyanotic patients. This calculation was made by taking the difference between the arterial and venous oxygen content at the time the defect was corrected. At this time the patient was still totally supported by the oxygenator and the venous blood had reached maximum desaturation. Since the patient's perfusion rates or "cardiac output" were known and constant, the total quantity of oxygen used by the patient per minute could be readily calculated. The basal respiratory quotient[8] of 0.82 was selected for the conversion factor of oxygen into calories, the value of which is 4.825 calories per liter of oxygen. Temperature also affects oxygen consumption and, as the heart tolerates surgery upon itself better at normal temperatures, these patients were maintained euthermic throughout the procedure by the addition of heat as necessary from an electric blanket under the patients and from the constant temperature water bath in which the oxygenator reservoir was mounted.

As the age and the weight of the patient are directly correlated with the oxygen consumption rate these values for each group have been plotted individually in Figs. 2 and 3, with the smallest patient in each group plotted to the left of the next larger sized patient. As can be noted the smaller the patient in each group the higher the oxygen consumption rate per kilogram of body weight, and Group C, which represents the smallest patients in this series, had the highest oxygen consumption rates. It can be noted that the cyanotic patients over all had a lower oxygen consumption rate than did the acyanotic patients. Table V also illustrates this in that the cyanotic patients did not desaturate their venous blood to the same degree as the acyanotic patients at comparable perfusion rates.

TABLE V. MAXIMUM DESATURATION OF POOLED VENOUS BLOOD SAMPLES* MEASURED DURING PERFUSION (VENOUS O_2 CONTENT AT TIME DEFECT CLOSED)

	ACYANOTIC PATIENTS			CYANOTIC PATIENTS	
	A	B	C	D	E
Perfusion rate (c.c./Kg./min.)	30-35	36-41	50-60	26-35	40-50
O_2 content (vol. per cent)	7.1	7.5	6.6	8.5	8.8
Per cent saturated	36.0	39.0	34.0	43.0	43.0

*Sampled from the patients' caval catheters.

Effect of the Pump Oxygenator Upon Blood Elements.—For many of the cases the perfusion apparatus was primed with freshly drawn arterialized venous blood[9] in heparin.* This blood closely approximates normal arterial blood in pH, CO_2 content, hemoglobin, and oxygen saturation. In other patients priming was carried out by arterializing freshly drawn heparinized venous blood by passage through the oxygenator to fill the helix reservoir.

Hemolysis.—The apparatus used in these patients produced a degree of hemolysis well within the range considered innocuous. There was often a direct relationship of hemolysis to duration of the perfusion, but the mean value for hemolysis did not vary in any definite manner in the various groups in relationship to perfusion rates. The mean hemolysis for all the cases was 33 mg. per cent plasma hemoglobin with a range from a low of 6 mg. per cent to a high of 80 mg. per cent.

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*18 mg. per 500 c.c. bottle.

Clotting mechanism: Platelet counts in this entire group of 80 patients averaged 266,000 per cubic millimeters preoperatively, the mean value for the determination made within two hours after the perfusion was 200,000 per cubic millimeters. The bleeding times preoperatively averaged four and one-half minutes and were the same for the determinations made within two hours after the perfusion. The control clotting times on these patients was four minutes, forty-five seconds with a five-minute clotting time as the mean value within two hours after the perfusion. Table VI summarizes these data.

TABLE VI. EFFECT OF TOTAL BY-PASS PERFUSIONS WITH PUMP-OXYGENATOR UPON THE CLOTTING ELEMENTS (MEAN VALUES FOR 80 PATIENTS)

	PLATELETS (CU. MM.)	BLEEDING TIME (MIN.)	CLOTTING TIME (MIN.)
Preoperative	266,000	4′ 30″	4′ 45″
Postperfusion*	200,000	4′ 30″	5′

*All determinations made within two hours after conclusion of actual perfusion.

Pressure Measurements.—In 2 adult patients continuous intraluminal arterial pressures were monitered throughout the perfusion. One patient with a ventricular septal defect, who received a perfusion rate of 34 c.c. per Kg. of body weight per minute, maintained a systolic arterial pressure of 75 mm. Hg or more throughout the entire procedure. The other patient with an aortic stenosis, perfused at 32 c.c. per Kg. per minute, maintained a systolic arterial pressure of 70 mm. Hg or better except for a short interval after the corrective procedure when the clamp which occluded the aorta was released at which time her pressure momentarily fell to 30 mm. Hg. Recovery in both patients was uneventful.

COMMENT

The oxygenator herein employed has proved to be efficient in the performance of the respiratory functions for these patients during their interval of total pulmonary by-pass. At all flow rates the oxygenation of the venous blood by this oxygenator was optimal (95 to 96 per cent) for perfusion of the arterial system (Table I). Moreover, the carbon dioxide content of the arterial blood returning to the patient from the oxygenator was consistently less than the control or normal values, indicating that this apparatus adequately removed the carbon dioxide of catabolism from the venous blood. This lowered arterial carbon dioxide content may be readily altered to normal by the simple addition of some carbon dioxide to the oxygenating gases. In this regard we have generally felt that some degree of carbon dioxide content depression was desirable in these patients to oppose the metabolic acidosis generally occurring in patients undergoing anesthesia and major surgical procedures.

However, recent investigations have indicated that the arterial carbon dioxide content is the principal humoral agent controlling the vasomotor tone in the cerebral circulation in man. In this regard, Gibbs and his associates,[10] and Kety and Schmidt[11] have pointed out that depressed arterial carbon dioxide levels decreased and high levels increased the cerebral blood flow. They also state that cerebral oxygen consumption was unchanged by the various concentrations of arterial carbon dioxide studied.

The patients herein studied undergoing total body perfusion utilizing the pump oxygenator invariably awakened immediately postanesthesia and appeared mentally alert and were completely free of any evidence of neurologic sequelae related to their perfusion interval. However, despite these gratifying clinical observations indicating the gross adequacy of the cerebral flow during the perfusions, it is of obvious importance to study more precisely the effects of various flow rates and of various partial pressures of arterial carbon dioxide in the perfusing blood utilizing electroencephalography to evaluate cerebral function. These studies are currently in progress.

In assessing acid-base balance in these patients no chemical means were used during or immediately after the by-pass interval to counteract fluctuations in hydrogen ion concentration. Thus, the observed data represent the patient's own reponses to perfusion and surgery influenced only by the abovementioned respiratory alkalosis. In regard to acid base balance, it is worthy of emphasis that blood pH values alone result in an incomplete picture inasmuch as they may be normal or even on the alkaline side of normal despite a gain of fixed acids in the blood. For this reason the alterations in response to perfusion in the total plasma bicarbonate, as a measure of the alkaline reserve, have been determined in these patients. All of our patients manifested a depression of their total plasma bicarbonate as a result of their interval of perfusion. This depression was due to an accumulation of fixed acids and can otherwise be expressed as the development of a compensated metabolic acidosis. All of our patients had mild elevations in blood lactate, but levels well below those found during exercise.[20, 21] The range of bicarbonate deficit developed in these patients varied from 3.3 mM per liter in the cyanotic group patients (Group D) to 6.7 mM per liter in the acyanotic patients (Group A). The normal daily variations in fixed acids have been reported to range from 2.7 mM per liter[12] to 4.0 mM per liter while values as high as 9.3 mM per liter have been found to occur during pulmonary surgery.[13]

A gain in fixed acids averaging 5.2 mM per liter has been found in children less than one year of age receiving ether anesthesia for general surgical procedures of only moderate magnitude such as herniorrhaphy or pyloromyotomy.[14] In 27 older children, undergoing similar type surgical procedures, the gain in fixed acids averaged 4.0 mM per liter. These authors concluded that a moderate acidosis of this degree was not harmful and of no practical significance. The same authors[14] presented evidence that this gain in fixed acids was due to the sympathomimetic effect of ether upon the adrenal medulla augmented in some of their patients by the intravenous administration of glucose and/or blood, both of which increase the fixed acid content of the patient. The injection of epinephrine alone is known to produce marked elevations of fixed acids.[19]

tients with acyanotic forms of heart disease). This depression was accompanied by a moderate elevation of blood lactic acid in almost all patients in which this measurement was made. Values for pH did not vary greatly from normal. Serum potassium values regularly decreased moderately during the perfusions.

These changes in bicarbonate, lactic acid, and potassium occurring during total body perfusion are qualitatively and quantitatively similar to the changes observed during the administration of epinephrine in physiologic quantities. It is believed that these changes in acid-base equilibria are the result of a reflex stimulation of the sympathetic nervous system rather than tissue hypoxia. No relationship was observed between this moderate bicarbonate depression and postoperative morbidity and mortality in this series of patients.

Preoperatively all patients with cyanotic heart disease were found to be in a state of metabolic acidosis under ambulatory conditions.

The smaller and younger patients had higher oxygen consumption rates during the perfusion as they do in normal states, therefore, they should receive higher perfusion rates than older children and adults during their procedures.

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Lam and co-workers[11] have reported the induction of cardiac arrest in hypothermic dogs by intraventricular injection of 5 per cent potassium chloride with survival after complete circulatory occlusion up to 30 minutes. In their experiments, restoration of normal rhythm was accomplished by cardiac massage and was apparently preceded routinely by ventricular fibrillation which required countershocks. In England, Melrose and his associates[12] have also reported preliminary experiments using potassium citrate to temporarily arrest cardiac action in isolated hearts and in the intact animal.

In studies to be reported elsewhere,[13] a search was made for a more satisfactory cardioplegic agent. Such an agent should show the following characteristics: (1) rapid induction of complete cardiac arrest, (2) complete lack of electrical and muscular cardiac activity during the cardioplegia, (3) rapid resumption of a normal cardiac beat on re-perfusion of the coronary vessels with blood, (4) absence of ventricular fibrillation, and (5) absence of toxicity if the entire dose gained entrance to the general circulation.

Various drugs and mixtures were tested by injection into the coronary perfusion system of isolated cat hearts in a Langendorff perfusion apparatus.[14] If cardiac arrest resulted, the perfusion was stopped for 10 minutes. The time required for resumption of normal beat on re-perfusion with a modified Ringer-Locke solution was noted, together with the type of electrocardiographic and muscular activity regained.

Briefly, it was found (Table I) that both potassium citrate and magnesium sulfate alone produced rapid cardiac arrest. The incidence of fibrillation following administration of the magnesium salt alone, however, made this drug undesirable. By combining the two agents, fibrillation was usually avoided and the concentration and quantity of potassium citrate could be reduced.

TABLE I. INDUCED CARDIAC ARREST IN THE ISOLATED CAT HEART

SOLUTION INJECTED (10 ML.)	NUMBER OF TRIALS	AVERAGE TIME TO ARREST BEAT (MIN.)	TIME TO RESUME BEAT* (MIN.)	INCIDENCE OF FIBRILLATION
K Cit. 1.6 per cent	5	0.6	2.1	0
$MgSO_4$ 3.69 per cent	7	1.2	1.2	3
†K Cit. $MgSO_4$	12	0.3	1.7	2
†K Cit. $MgSO_4$ + 10 mg. Benadryl	7	1.0	1.7	0
†K Cit. $MgSO_4$ + 12.5 mg. Pyribenzamine	7	1.0	1.9	0
†K Cit. $MgSO_4$ + 0.5 mg. Prostigmin	7	0.6	3.5	0

*All hearts cardioplegic for ten minutes. No appreciable change from original electrocardiogram pattern after good beat established.

†0.54 Gm. potassium citrate and 2.47 Gm. magnesium sulfate per 100 ml. adjusted to pH 7.4 with sodium bicarbonate. (200 meq./L. magnesium and 50 meq./L. potassium.)

Using these data, a basic solution was evolved containing 2.47 Gm. per cent magnesium sulfate ($MgSO_4 \cdot 7H_2O$) and 0.54 Gm. per cent potassium citrate [$K_3(C_6H_5O_7) \cdot H_2O$] brought to pH 7.4 with sodium bicarbonate. The addition of small quantities of Prostigmin or one of the antihistaminics[15] seemed to

A METHOD FOR CONTROLLED CARDIAC ARREST AS AN ADJUNCT TO OPEN HEART SURGERY

W. Glenn Young, Jr., M.D. (by invitation), Will C. Sealy, M.D., Ivan W. Brown, Jr., M.D. (by invitation), Wilmer C. Hewitt, Jr., M.D. (by invitation), Henry A. Callaway, Jr., M.D. (by invitation), Doris H. Merritt, M.D. (by invitation), and Jerome S. Harris, M.D. (by invitation)
Durham, N. C.

As experimental and clinical evidence accumulates, it is becoming apparent that the unhurried and precise repair of many intracardiac defects will require the use of a mechanical pump and oxygenator. Maintenance of the coronary and systemic circulation for short periods can be achieved safely with reduced flow rates as shown by Lillehei and his associates.[1] The addition of hypothermia to this technique would appear desirable if the danger of irreversible cardiac arrhythmias during ventriculotomy can be eliminated.

When cardiotomy is performed during arterial perfusion, however, blood loss through the coronary sinus and regurgitation through the aortic valve may be profuse and would make direct procedures on the aortic valve or within the left ventricle almost impossible. This difficulty can be overcome by occluding the ascending aorta in addition to the venae cavae, thus rendering the heart totally ischemic. The contracting, normothermic heart can safely withstand this maneuver only one to 3 minutes.[1, 2] Hypothermia to 25° C. apparently increases this safe time limit only slightly; to 5 or 6 minutes.[3, 4]

Induced cardiac arrest by decreasing cardiac metabolism would *theoretically* allow more prolonged aortic and coronary occlusion. The advantages of a dry, motionless operative field free from danger of air embolism are apparent.

It has been known since the time of Ringer[5] that an excess of potassium ion in the coronary circulation will cause the heart to stop in diastole. Hooker,[6] Wiggers,[7] and more recently Swan[2] have injected potassium salts into the heart to stop ventricular fibrillation. Senning[8] attempted to temporarily inhibit the cardiac contractions by injections of potassium chloride, acetylcholine, Mecholyl, and related compounds but was unsuccessful apparently because he maintained coronary perfusion and immediately washed out or diluted the cardioplegic agent. His technique of initiating fibrillation prior to cardiotomy is helpful in preventing air embolism but would not theoretically allow prolonged inflow and outflow occlusion because the metabolism of the fibrillating heart may actually be higher than normal.[9, 10]

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†K Cit $MgSO_4$ + 10 mg Benadryl	7	1 0	1 7	0
†K Cit $MgSO_4$ + 12 5 mg Pyribenzamine	7	1 0	1 9	0
†K Cit $MgSO_4$ + 0 5 mg	-			

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†0 54 Gm potassium citrate and 2 47 Gm magnesium sulfate per 100 ml adjusted to pH 7 4 with sodium bicarbonate (200 meq /L magnesium and 50 meq /L potassium)

Using these data, a basic solution was evolved containing 2 47 Gm per cent magnesium sulfate ($MgSO_4 \cdot 7H_2O$) and 0 54 Gm per cent potassium citrate [$K_3(C_6H_5O_7) \cdot H_2O$] brought to pH 7 4 with sodium bicarbonate The addition of small quantities of Prostigmin or one of the antihistaminics[15] seemed to further decrease the incidence of fibrillation in the isolated cat heart. The bradycardia produced by Prostigmin also theoretically decreases metabolism during the critical period after resumption of cardiac activity.

The results were then applied to a series of normothermic and hypothermic dogs undergoing right ventriculotomy with inflow and outflow tract occlusion for varying periods of time.

EXPERIMENTAL DATA

Methods.—Prior to each experiment, 100 ml. of the magnesium sulfate-potassium citrate solution was prepared and the pH adjusted to 7.4 with sodium bicarbonate. In the majority of instances, Prostigmin (1 mg. per 100 ml.) was added to the solution.

Dogs weighing 9 to 20 Kg. were anesthetized with sodium pentobarbital (30 mg. per Kg.) and artificial respiration begun at a rate to ensure moderate hyperventilation. When hypothermia was desired, this was accomplished by immersion in ice water. Rectal temperatures in the hypothermic animals ranged from 24°-28° C. The right chest was entered and the azygos vein ligated. Tourniquets were placed about the venae cavae and through the transverse pericardial sinus about the aorta and pulmonary artery. A purse-string suture of fine silk was placed in the adventitia of the proximal aorta in order to prevent bleeding from the injection site. As the inflow and outflow tourniquets were tightened the cardioplegic solution was rapidly injected into the aorta through a No. 20 needle with a slightly curved tip. Care was taken that the needle tip remained distal to the aortic valve cusps. The injection was continued until all visible cardiac contractions ceased and the heart failed to respond to mechanical stimulation of the ventricle. The needle was then withdrawn and the hemostatic suture tied. With the heart motionless and empty, right ventriculotomy was performed and repaired in a leisurely fashion.

After completing the cardiotomy, the outflow tourniquet was loosened and coronary perfusion resumed. In the acute experiments to be discussed, the brain was protected by hypothermia during the period of circulatory arrest and the cardioplegic solution washed out with oxygenated Ringer's solution introduced under pressure through a Foley-type catheter in the subclavian and brachiocephalic artery. During this period of time, the right auricle was opened to allow egress of the perfusion fluid and prevent overdilatation of the heart. When satisfactory cardiac rhythm resumed, the coronary circulation was primed with oxygenated blood through the catheter, and the venae cavae opened slowly. After removing the catheter, the animal was observed for varying periods of time.

Physiologic studies undertaken during these experiments included electrocardiography, femoral arterial blood pressures, and determinations of blood pH, sodium, potassium, magnesium, chloride, and carbon dioxide.

More recently using a simple extracorporeal pump-oxygenator system[16] to maintain the systemic circulation, cardiac activity was restored simply by releasing the outflow tourniquet and allowing coronary perfusion to resume with oxygenated blood.

RESULTS

Fourteen acute experiments were performed on hypothermic dogs, each undergoing right ventriculotomy. One and six-tenths per cent potassium citrate was used to induce cardiac arrest in 6 of the animals and the potassium citrate-magnesium sulfate-Prostigmin mixture in eight of the experiments. The quantity of drug injected averaged 21 c.c. for potassium citrate and 24 c.c. in the potassium-magnesium-Prostigmin group. Duration of complete cardiac ischemia (outflow occlusion) ranged from 6 to 14 minutes (average 9.4 minutes). Resumption of regular cardiac rhythm occurred in 13 of the animals following coronary perfusion with Ringer's solution. Ventricular fibrillation developed in the first experiment when difficulty with the perfusion catheter occurred and resuscitation was attempted by cardiac massage. Two of the dogs (both in the potassium citrate group) subsequently developed ventricular fibrillation prior to completing the operative procedure. This low incidence of fibrillation in the hypothermic animals seemed quite remarkable to us considering the crude method of coronary perfusion and the surgical manipulations undertaken.

The time required for return of a satisfactory heartbeat in these experiments ranged from 2 to 10 minutes (average 4.7 minutes). The 11 dogs surviving the operative procedure maintained a satisfactory blood pressure and electrocardiographic pattern until sacrificed 30 minutes to 9 hours later. To test the toxicity of the solution, 3 of these animals were given a second injection of the cardioplegic agent rapidly by systemic vein during the observation period. Except for a temporary fall in blood pressure and bradycardia, this injection was tolerated well.

Survival experiments performed in combination with the pump-oxygenator system have confirmed our initial impression of the feasibility of this technique. The ease of resuming coronary perfusion by simply releasing the aortic tourniquet greatly simplifies the procedure, and no other resuscitative efforts are necessary. Table II summarizes the results in ten experiments employing the pump-oxygenator and one in which coronary perfusion was re-established with Ringer's solution under sterile conditions. The longest period of total inflow and outflow occlusion without serious arrhythmia and with long-term survival has been 21 minutes. The upper limits of tolerance have not been established as yet. From these early observations, it appears that the time required to resume normal cardiac activity is directly proportional to the duration of ischemia, but the factor of coronary flow rates may be significant. During this interval, support of the systemic and coronary circulations must be accomplished by the artificial heart-lung apparatus. Although normal cardiac rhythm was re-established in all animals, deaths occurred in several due to secondary hypotension or failure to regain consciousness. This mortality has been attributed to prolonged extracorporeal circulation at flow rates which are now considered inadequate.

Electrocardiographic tracings of one of the surviving dogs are depicted in Fig. 1. After 11 minutes of complete ischemia, the heart
normal electrocardiogram within one minute after resuming cc

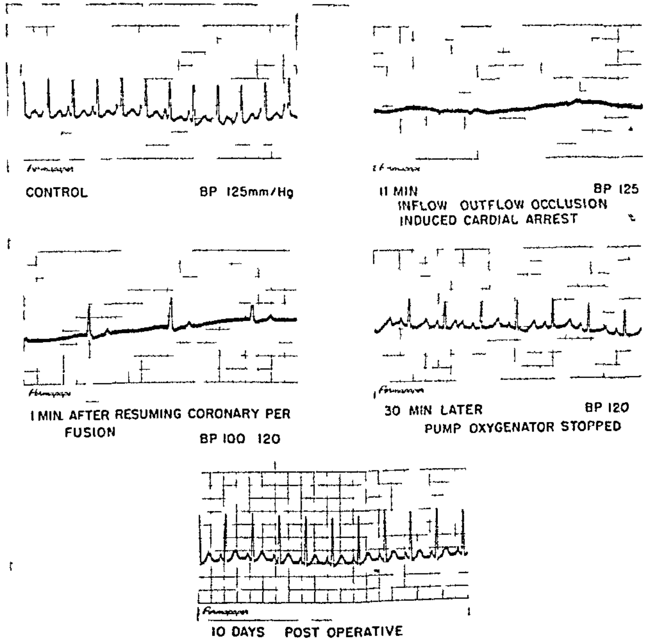
TABLE II. RESULTS IN DOGS UNDERGOING RIGHT VENTRICULOTOMY DURING INDUCED CARDIAC ARREST

WEIGHT OF DOG (KG.)	LOWEST TEMPERATURE (° C.)	SOLUTION* INJECTED	AORTIC OCCLUSION (MIN.)	TIME TO GOOD BEAT (MIN.)	VENTRICULAR FIBRILLATION	MAXIMUM SERUM LEVEL MEQ./L.		COMMENT
						POTASSIUM	MAGNESIUM	
9.1	24	30 c.c. K-M-P	6.5	8	0	3.9	4.8	Fibrillation 100 min. later during secondary hypotension
18.0†	27	15 c.c. 1.6 % K. Cit.	8.0	3	0	5.0	--	Recovery
9.3	27	10 c.c. K-M-P	9.0	2	0	5.9	3.0	Died 7 hours later; failed to regain consciousness
8.4	26	25 c.c. K-M-P	10.0	9	0	5.9	6.0	Recovery
8.0	27	45 c.c. K-M-P	21.0	16	0	6.1	4.8	Recovery
13.0	34	30 c.c. K-M-P	5.0	1	0	4.3	2.1	Died of hemorrhage 8 hours later
14.0	31	60 c.c. K-M-P	8.0	11	Transient (air embolus)	4.3	4.7	Recovery
9.4	32	35 c.c. K-M-P	10.0	1	0	3.2	2.4	Lived 24 hours with brain damage
9.0	32	25 c.c. K-M-P	10.0	1	0	5.1	6.1	Died 5 hours later; hypotension and brain damage
15.0	31	30 c.c. K-M-P	11.0	1	0	4.6	5.1	Recovery
11.0	34	50 c.c. K-M-P	12.5	12	0	5.2	4.2	Secondary hypotension 2½ hours after procedure with death

*K-M-P refers to potassium citrate-magnesium sulfate-Prostigmin mixture (see text).
†Coronary perfusion re-established with Ringer's solution.

In other experiments, varying degrees of auricular ventricular block with bizarre QRS complexes were noted during the recovery period. These conduction disturbances vanished as the perfusion continued and the potassium and magnesium of the cardioplegic solution were washed away.

Elevation of serum potassium and magnesium was minimal despite the fact that no especial effort had been made to prevent entry of the cardioplegic solution into the general circulation in many of these experiments. The highest potassium and magnesium levels noted following resumption of cardiac activity are not within the generally accepted toxic range.



CONTROL BP 125mm/Hg

11 MIN BP 125
INFLOW OUTFLOW OCCLUSION
INDUCED CARDIAL ARREST

1 MIN. AFTER RESUMING CORONARY PERFUSION BP 100 120

30 MIN LATER BP 120
PUMP OXYGENATOR STOPPED

10 DAYS POST OPERATIVE

Fig 1 —Electrocardiogram (Lead II) of dog undergoing right ventriculotomy with controlled cardiac arrest.

The blood entering the right auricle during coronary perfusion but prior to resumption of cardiac activity appeared well saturated with oxygen. Although no definite conclusion concerning the oxygen consumption of cardiac muscle during induced arrest can be made without flow measurements, the marked decrease in femoral arterial coronary sinus oxygen difference as determined in seven experiments seems significant (Table III).

TABLE II. RESULTS IN DOGS UNDERGOING RIGHT VENTRICULOTOMY DURING INDUCED CARDIAC ARREST

WEIGHT OF DOG (KG.)	LOWEST TEMPERATURE (° C.)	SOLUTION* INJECTED	AORTIC OCCLUSION (MIN.)	TIME TO GOOD BEAT (MIN.)	VENTRICULAR FIBRILLATION	MAXIMUM SERUM LEVEL MEQ./L.		COMMENT
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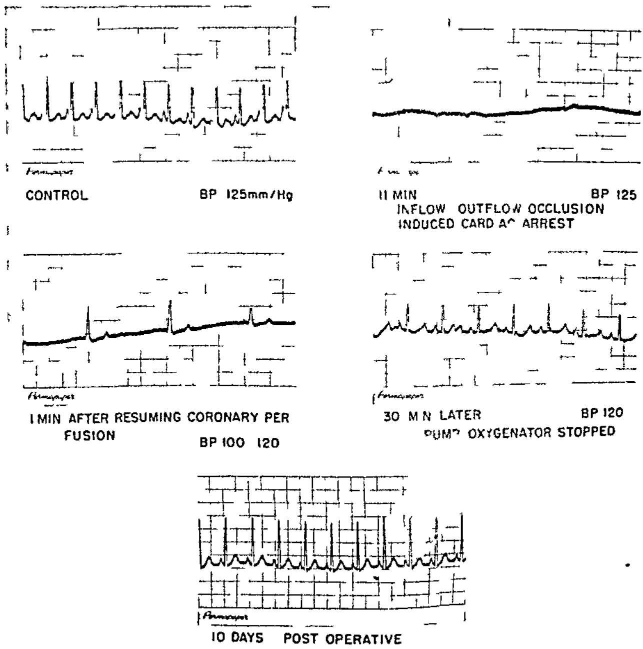

Fig 1.—Electrocardiogram (Lead II) of dog undergoing right ventriculotomy with controlled cardiac arrest.

The blood entering the right auricle during coronary perfusion but prior to resumption of cardiac activity appeared well saturated with oxygen. Although no definite conclusion concerning the oxygen consumption of cardiac muscle during induced arrest can be made without flow measurements, the marked decrease in femoral arterial coronary sinus oxygen difference as determined in seven experiments seems significant (Table

TABLE III. FEMORAL ARTERIAL-CORONARY SINUS OXYGEN DIFFERENCES (VOLS. %)

EXPERIMENT NUMBER	1	2	3	4	5	6	7	AVERAGE
Inflow occlusion; heart beating; perfusion with pump-oxygenator before cardiac arrest	62.0	47.3	10.3	50.0	59.2	14.4	47.5	41.5
Inflow occlusion; immediately after resumption of coronary perfusion but prior to return of heartbeat	5.4	2.3	5.4	4.7	7.5	0.0	0.0	3.6

DISCUSSION

These results confirm and extend the experiments of Melrose and Lam and further demonstrate the feasibility of elective cardiac arrest as an adjunct in open-heart surgery. Because of the variable time necessary for resumption of adequate cardiac activity, this technique must always be used in conjunction with a satisfactory pump-oxygenator to maintain the systemic circulation whether or not hypothermia is present. It is noteworthy that the danger of serious arrhythmia during ventriculotomy in the hypothermic animal is almost abolished by this technique. This finding opens up a new avenue for investigation concerning the merits of moderate hypothermia in conjunction with the low flow pump-oxygenator techniques advanced by Lillehei.

Whether the magnesium sulfate-potassium citrate-Prostigmin solution is superior to potassium chloride or potassium citrate alone in inducing cardiac arrest in the intact animal must await further study. It is well known that both potassium and magnesium stop the heart in diastole. The combination lessens the danger of systemic toxicity from either one alone. The addition of an antifibrillatory drug such as Prostigmin seems warranted, especially, as previously mentioned, in view of the resultant bradycardia on recovery.

The metabolism of the heart during induced arrest appears to be different from normal because it can withstand complete ischemia for longer periods of time than the beating heart without apparent damage. The maximum period of total inflow-outflow occlusion with long-term survival in these experiments was 21 minutes in the hypothermic animals and 11 minutes in animals not previously refrigerated. The upper limit of total ischemia which can be tolerated safely using this technique has not been established as yet. Rohde[17] found that the metabolism of the arrested heart was less than one half that of the normally contracting heart. The results of our determinations of arteriovenous oxygen difference are suggestive of a marked decrease in metabolism during arrest. This problem is being investigated further.

SUMMARY

Following experiments on the isolated cat heart, controlled cardiac arrest, using a solution of magnesium sulfate and potassium citrate, was induced in a group of normothermic and hypothermic dogs undergoing right ventricu-

lotomy It was found that this technique is feasible in allowing recovery after prolonged periods of complete cessation of the coronary circulation and in preventing serious arrhythmias during cardiotomy

The application of this method to cardiac surgery is discussed

ADDENDUM

This method of controlled cardiac arrest has been used in 2 patients operated upon with temperatures of 30° C and 31° C, respectively Normal heart action returned in both One case, a 2 week old infant, died because of an irreparable anomaly an hour after induced standstill The other, a 7 year old boy who had both ventricular and auricular septal defects closed, survived twenty three minutes of extracorporeal circulation and seventeen minutes of cardiac standstill Though he regained consciousness and had normal blood pressure, he died twelve hours later from the results of irreversible vascular changes in the lung

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THE NEUTRALIZATION OF HEPARIN BY PROTAMINE IN EXTRACORPOREAL CIRCULATION

RAYMOND HURT, M.B., F.R.C.S.* (BY INVITATION), HERBERT A. PERKINS, M.D. (BY INVITATION), JOHN J. OSBORN, M.D. (BY INVITATION), AND
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AT THE conclusion of a heart-lung by-pass with an extracorporeal circulation, it is necessary to neutralize the anticoagulant action of the heparin with protamine. If this is not done adequately, continued hemorrhage will occur and lead to an extensive hemothorax. During the course of studies in extracorporeal circulation in dogs, it became apparent that the protamine itself may cause several side effects; it may cause an increase in the clotting time if given in excess, it may cause a shocklike syndrome, or it may cause a thrombocytopenia. At the conclusion of the by-pass, it is therefore important to avoid an overdose of protamine, and to give only sufficient to neutralize the heparin that is circulating in the blood at that time. A method of protamine titration has been developed in order to estimate the correct dose, and it is the purpose of this paper to describe this method of protamine titration briefly, and then to present data which demonstrate some of the undesirable side effects of the intravenous injection of protamine.

A METHOD OF PROTAMINE TITRATION

It is difficult to estimate the correct dose of protamine for the following reasons: (1) The dose of protamine required to neutralize heparin in vivo is not the same dose as is required for its neutralization in vitro, (2) preparations of heparin and protamine vary greatly in their effect and, (3) the quantity of protamine required to neutralize a given dose of heparin will decrease with increasing time from the point of heparin injection. Therefore, a method of protamine titration in vivo has been developed in order to estimate the required dose.

The method is briefly as follows: The protamine that is to be used subsequently is set up in 11 small tubes in concentrations of from zero to 50 mcg. in a volume of 0.1 ml. One milliliter of blood is added to each tube, which is inverted once to mix its contents. The tubes are inspected at the end of 15 minutes to see which have clotted. The dose of protamine required to neutralize the

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*Traveling Fellow of The American Association for Thoracic Surgery.

heparin in the circulating blood is then calculated by taking the concentration of protamine in the tube that has clotted with the least amount of protamine and multiplying this concentration by the estimated blood volume of the dog (Fig 1)

This method of protamine titration[1] has demonstrated that in the past a considerable excess of protamine has often been given It has also shown how easy it is to prolong the clotting time of the blood by a relatively small over dose of protamine

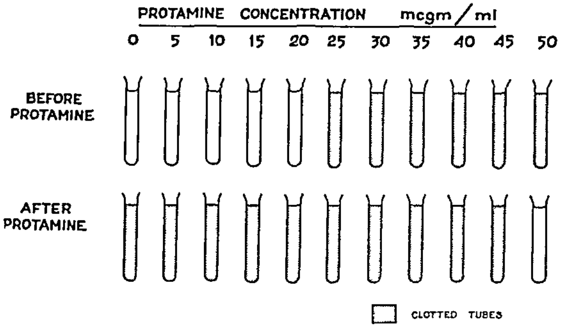

Fig 1 —An example of a protamine titration The upper row of tubes shows that a clot formed in those which contained protamine in concentrations greater than 25 micrograms per milliliter The dose of protamine required by the dog can be estimated by the method *described in the text*

The lower row of tubes demonstrates a second confirmatory titration and shows how an excess of protamine in the tube at the extreme right prevented the formation of any clot

THE EFFECT OF EXTRACORPOREAL CIRCULATION ON PROTAMINE SHOCK

The occurrence of a toxic reaction following the rapid intravenous injection of protamine was reported by Japelli[2] and subsequently by other workers[3] This toxic reaction is manifest by a fall in blood pressure and an increase in the depth and rate of respiration When it occurs at the conclusion of a heart lung by pass the animal may pass into a state of shock from which it may never recover However, the reaction is very variable and depends on the species of animal, the dose of protamine, and even on whether or not the animal is anesthetized In the dog, for example, 2 mg protamine per kilogram of body weight will result in a temporary fall in blood pressure if the animal is anesthetized, whereas the same dose to an unanesthetized animal will cause no reaction The reports of different workers are contradictory, however, and this may be accounted for by a difference in the source, and therefore the method of manufacture, of the protamine

Despite these variable and, at times, conflicting reports, it appeared that the reaction which followed the injection of protamine into the normal dog was very much less severe than that which so often occurred following its use at the conclusion of a heart lung by-pass with an extracorporeal pump oxygenator It is known that there may be considerable damage to the blood during its passage through an extracorporeal circuit and it was thought that this might have some connection with the occurrence of a more severe reaction to the protamine. In fact, the severity of the reaction might be an indication of the extent of such damage.

In order to ascertain whether or not this was true, a study was made of the effect of an intravenous injection of a standard dose of protamine into normal heparinized dogs. This was compared to the effect of a comparable dose of protamine into dogs whose blood had been passed through an extracorporeal pump.

METHOD

Adult mongrel dogs weighing between 6 and 11.5 Kg. were used. They were anesthetized with intravenous Nembutal, 30 mg. per kilogram of body weight.

Effect of Protamine on Normal Dogs.—Heparin (Upjohn heparin sodium, 10 mg. per milliliter) was given intravenously in a dose of 2 mg. per kilogram body weight. Forty-five minutes later an approximately neutralizing dose of protamine, 1 mg. protamine per milligram heparin (Eli Lilly protamine sulphate, 1 per cent), was injected intravenously over a period of about 3 seconds and the effect on the blood pressure and pulse rate noted on a continuously recording oscillograph.

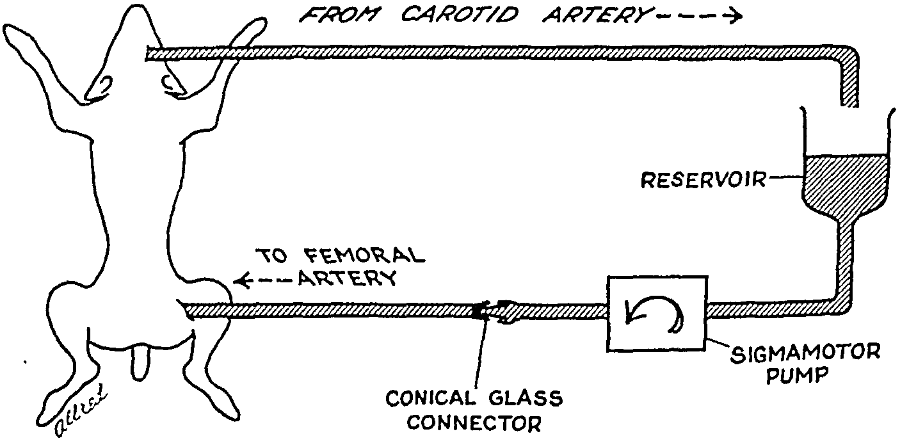

Fig. 2.—Schematic diagram of the apparatus used to produce a traumatic perfusion.

Effect of Protamine on Dogs Whose Blood Had Been Damaged by Passage Through an Extracorporeal Pump.—Heparin was given intravenously to these dogs in a similar dose to that used in the normal animals. The pump system that was used to traumatize the blood is shown diagrammatically in Fig. 2. Blood from the carotid artery was collected in a reservoir from which it was pumped back into the femoral artery by a Sigmamotor pump. In order to increase the resistance against which the pump had to work and so produce an adequate amount of damage to the blood, a conical glass connecting piece was inserted in the circuit between the pump and the femoral artery. The rate of flow was 250 to 480 ml. per minute and the time of perfusion was 30 to 45 minutes. Five minutes after the perfusion was completed the appropriate dose of protamine was given intravenously over a period of 3 seconds and the effect on the blood pressure and pulse rate noted as before. The degree of damage to the blood was assessed by plasma hemoglobin estimations at intervals during the course of the perfusion.

RESULTS

Effect on Normal Dogs.—Observations were made on 12 dogs. A typical response to the intravenous injection of protamine (in a dosage of 2 mg. per kilogram of body weight) is shown in Fig. 3. About 25 seconds after the injection, there was a sudden fall in blood pressure from 200/160 to 130/80 mm. Hg lasting for 6 seconds, following which it gradually rose to its original level in 18 seconds. This type of response was obtained in 9 dogs. The blood pressure remained low for 6 to 20 seconds and returned to normal in 15 to 50 seconds. In some cases, there was also a definite bradycardia lasting for up to 15 seconds (Fig. 4). This may be called a normal reaction in an unperfused dog.

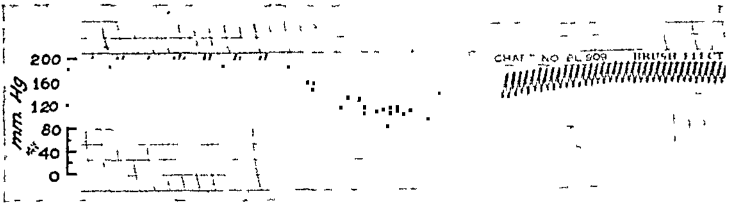

Fig. 3.—A typical protamine reaction in a normal dog showing the brief duration of the hypotension.

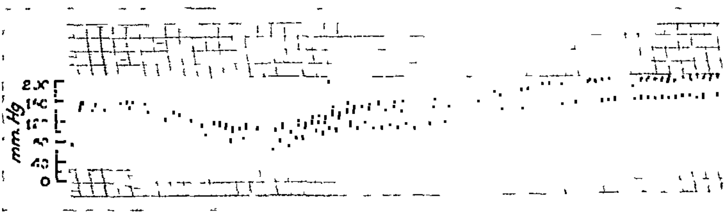

Fig. 4.—A protamine reaction in a normal dog showing a transitory bradycardia.

In 3 dogs the reaction was more severe. The blood pressure remained low for one-half to 2 minutes and did not return to normal for 2 to 5 minutes. The fall in blood pressure was accompanied by a slight but definite bradycardia.

Effect on Perfused Dogs.—Observations were made on 14 dogs. The degree of hemolysis produced by the Sigmamotor pump varied between 10 and 24 mg. hemoglobin per cent after a perfusion lasting 30 minutes, and between 20 and 78 mg. hemoglobin per cent after a perfusion lasting 45 minutes, except in one case in which there was an extreme degree of hemolysis of 1,440 mg.

hemoglobin per cent. A typical reaction to the intravenous injection of the protamine is shown in Fig. 5. About 30 seconds after the injection there was a sudden fall in blood pressure from 180/140 to 100/80 mm. Hg lasting for 2 minutes, following which it gradually rose until it was back to normal in 8 minutes. In some cases, especially those in which there was a less prolonged fall in blood pressure, there was a very definite bradycardia which persisted for several minutes after the blood pressure had returned to normal (Fig. 6).

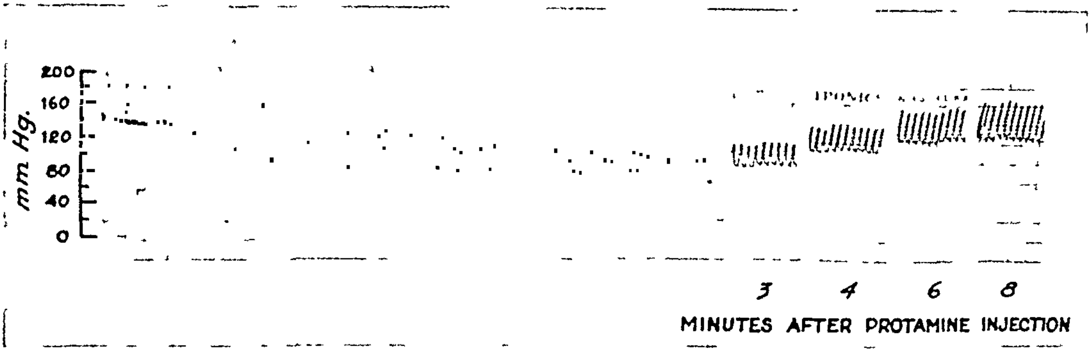

Fig. 5.—A typical protamine reaction in a perfused dog, showing a prolonged period of hypotension.

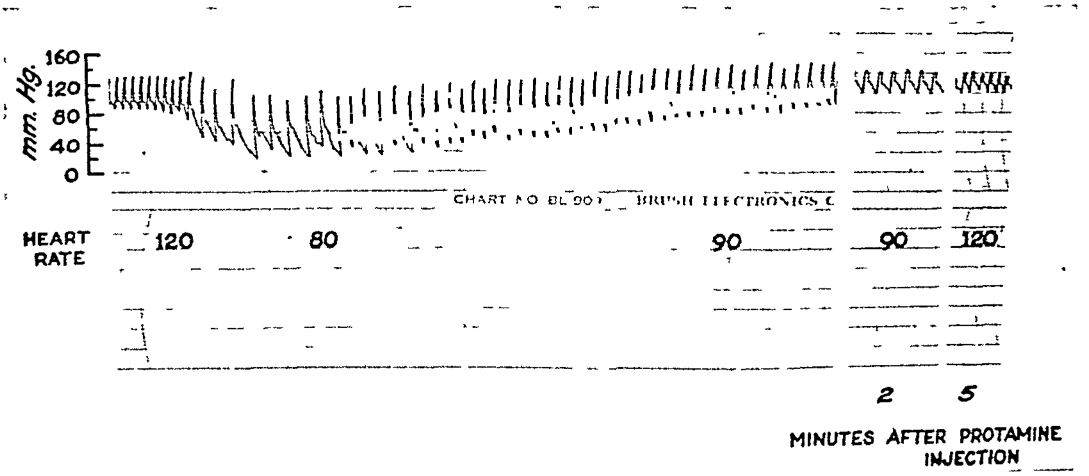

Fig. 6.—A protamine reaction in a perfused dog, showing a period of bradycardia.

These two types of severe reaction were obtained in 9 dogs; in 7 the blood pressure remained low for one-half to 16 minutes and did not return to normal for 2 to 26 minutes, while in 2 the fall was within the limits of a normal response in an unperfused dog, but none the less a very marked bradycardia developed, lasting for 2 and 5 minutes, respectively.

A slight reaction resembling that already described as the normal response in an unperfused dog occurred in 3 cases. The blood pressure remained low for 5 to 15 seconds and returned to normal in 15 to 40 seconds.

A more marked reaction, but one that was not sufficiently great to be classified as severe, was obtained in 2 dogs.

A statistical analysis of these results (using Kendall's t for tied ranks[9]) shows that they are significant (significance at 2 per cent level) and that a severe reaction occurred more frequently in the case of the perfused dogs

DISCUSSION

The rapid injection of protamine intravenously has been shown to cause a pronounced fall in blood pressure, the severity of which depends on whether or not the blood has been damaged by passage through an extracorporeal circuit It may also cause a very definite bradycardia, both in the normal and in the perfused dog The duration of this bradycardia is variable, it may last for only a few seconds, even though the blood pressure is still low, or it may last for several minutes after the blood pressure has returned to its original level The severity of the bradycardia is independent of the change in blood pressure and it would therefore appear likely that they are not associated This is in agreement with Jaques' view[6] that the fall in blood pressure is due to an arteriolar dilatation since the physiologic effect of such a change would be a quickening rather than a slowing of the pulse rate As far as is known, this bradycardia has not previously been reported as part of the toxic reaction to protamine

The severity of the reaction to protamine does not appear to correspond to the degree of damage to the blood as judged by plasma hemoglobin estimations though, of course, this estimation only measures one aspect of blood damage It is interesting to note that in the one case in which the blood was intentionally damaged very severely (plasma hemoglobin of 1 440 mg per cent after 45 minutes) there was a fall in blood pressure lasting only 15 seconds

The results of the investigation are summarized in Table I which shows that 9 out of the 14 perfused dogs (64 3 per cent) developed a severe reaction, as compared with 3 out of the 12 unperfused dogs (25 per cent) These results are statistically significant and show that the severe reaction occurred more commonly in the perfused dogs

TABLE I

REACTION	NORMAL DOGS	PERFUSED DOGS
Slight	9	3
Moderate	0	2
Severe	3	9
Total	12	14

Protamine is probably less toxic to man than it is to dogs[6, 8] but nevertheless it is possible that a more severe reaction might occur following the administration of protamine at the conclusion of a heart lung by pass in human beings The effect of the consequent hypotension and bradycardia would be exaggerated by the open thoracotomy and might well weigh heavily against the survival of the patient

As the reaction is likely to be less severe if the protamine is given slowly, it is considered advisable for the drug to be given over a period of several minutes

TABLE II. THE EFFECT OF PROTAMINE ON NORMAL DOGS

DOG NO.	FALL IN BLOOD PRESSURE (MM. HG)		TIME OF MAIN FALL IN BLOOD PRESSURE	TIME UNTIL NORMAL BLOOD PRESSURE	BRADYCARDIA*	REACTION
	FROM	TO				
1	200/160	130/80	6 sec.	18 sec.	0	Slight
7	200/130	120/50	2 min.	4 min.	+	Severe
8	180/100	140/60	10 sec.	20 sec.	0	Slight
11	140/90	90/40	12 sec.	20 sec.	0	Slight
12	160/120	120/80	18 sec.	25 sec.	0	Slight
19	140/100	60/40	20 sec.	50 sec.	0	Slight
20	160/120	100/60	10 sec.	40 sec.	0	Slight
21	180/140	100/70	30 sec.	2 min.	+	Severe
22	160/120	40/10	30 sec.	5 min.	+	Severe
23	180/120	110/70	15 sec.	45 sec.	0	Slight
24	140/100	80/40	10 sec.	50 sec.	0	Slight
26	160/100	100/60	15 sec.	40 sec.	0	Slight

*Bradycardia: + = lasted for 1 minute or less.

TABLE III. THE EFFECT OF PROTAMINE ON PERFUSED DOGS

DOG NO.	TIME OF PERFUSION (MIN.)	PLASMA HGB. AFTER PERFUSION (MG. %)	FALL IN BLOOD PRESSURE (MM. HG)		TIME OF MAIN FALL IN BLOOD PRESSURE	TIME UNTIL NORMAL BLOOD PRESSURE	BRADYCARDIA*	REACTION
			FROM	TO				
2	30	10	180/130	150/60	5 sec.	15 sec.	++++	Severe
3	30	18	140/100	80/50	16 min.	26 min.	+	Severe
4	30	22	190/140	160/70	10 sec.	30 sec.	+	Intermediate
5	30	24	200/150	150/100	10 sec.	30 sec.	0	Slight
6	30	10	200/130	120/50	30 sec.	80 sec.	+	Intermediate
9	45	1440	180/?	100/?	5 sec.	15 sec.	0	Slight
10	45	25	180/140	100/80	2 min.	8 min.	0	Severe
13	45	25	180/130	130/100	50 sec.	5 min.	0	Severe
14	45	31	140/100	90/70	30 sec.	2 min.	++++	Severe
15	45	20	140/100	100/60	15 sec.	40 sec.	+	Slight
16	45	32	160/?	80/?	2 min.	7 min.	0	Severe
17	45	78	180/110	80/20	10 sec.	20 sec.	++	Severe
18	45	36	160/100	80/30	1½ min.	10 min.	+	Severe
25	45	40	150/100	80/40	2 min.	11 min.	+	Severe

*Bradycardia: ++++ = lasted for 5 minutes.
++ = lasted for 2 minutes.
+ = lasted for 1 minute or less.

THE EFFECT OF PROTAMINE ON PLATELETS

In seven of the above experiments, platelet counts were carried out immediately before and, at short intervals, after the injection of the protamine. In each case there was a marked fall in the platelet count, the severity of which correlated well with the degree of shock produced. This thrombocytopenia following the administration of protamine was demonstrated by Jaques,[6] in 1949. It is not known whether the fall in platelet count is the cause or the result of the drop in blood pressure, but further investigations are in progress to elucidate this point.

SUMMARY

A method of protamine titration has been described by which it is possible to estimate the correct dose of protamine at the conclusion of a heart-lung by-pass.

A study has been made of the effect of the intravenous injection of a standard dose of protamine (2 mg per kilogram of body weight) on normal dogs, and also on dogs whose blood has been damaged by passage through an extra corporeal circuit

The protamine has been found to cause a fall in blood pressure and a bradycardia which occur independently of each other The severity of the reaction is variable, but is much more marked in those dogs whose blood has been damaged by passage through an extracorporeal circuit

The effect of protamine on platelets is briefly discussed

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DISPOSABLE MEMBRANE OXYGENATOR (HEART-LUNG MACHINE) AND ITS USE IN EXPERIMENTAL SURGERY

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INTRODUCTION

OPERATIONS in the open heart at normal body temperature require heart-lung machines as a substitute for cardiopulmonary function (Fig. 1). It was believed for a long time that the machine would have to pump and oxygenate blood in amounts equal to the normal resting cardiac output—at least 100 ml. per kilogram of body weight per minute. However, Andreasen and Watson[1, 2] in England have shown that dogs survived at least 35 minutes of occlusion of both venae cavae when only the azygos vein was left open and cardiac output was reduced to 10 to 18 ml. per kilogram of body weight per minute. Lillehei, Varco, and co-workers[3-7] have greatly advanced cardiac surgery in this country by using this principle. In dogs, they found that flow rates of 30 to 45 ml., as provided by cross circulation or some type of artificial heart-lung apparatus, were more suitable than the ''azygos flow'' rates of 10 to 18 ml. per kilogram per minute. Their successful experience with more than 110 patients has established the principle and the procedure as being clinically valid.

The possibility of using a small-flow rate revived the old idea of oxygenating blood in an apparatus using membranes. The advantages are obvious: there are no air bubbles, the possibility of air embolism is excluded; blood is not exposed to foam or screens or metal, so that potential sources of fibrin formation are eliminated.

During the earliest experience with the rotating type of artificial kidney in human beings, Kolff and Berk[8] observed that blue blood which entered the machine would become red during its course through the dialyzing tubing. Brubaker and Kammermeyer[9] compared the gas permeabilities of various membranes and found that polyethylene is permeable to both oxygen and CO_2. Clowes and associates[10] showed that the oxygenation of blood through a membrane of polyethylene of 1-mil thickness is much better than that through a membrane of 1.5-mil thickness. Kolff and Balzer[11] demonstrated a disposable artificial lung, later described in detail,[12] at the first meeting of the American Society for Artificial Internal Organs in 1955. It is based on the principle of oxygenation through a polyethylene membrane. One lung unit will oxygenate

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75 ml. of blood per minute; this, at a flow rate of 35 ml. per kilogram of body weight per minute, corresponds to the requirements of a 2-Kg. dog. By placing more than one unit in parallel, we can adapt the apparatus to dogs (or to children) weighing from 2 to 21 Kg. (4 to 47 pounds). During use, each lung unit holds 500 ml. of blood. Recent refinements in manufacture have reduced the amount of blood necessary to fill each unit to 270 ml.

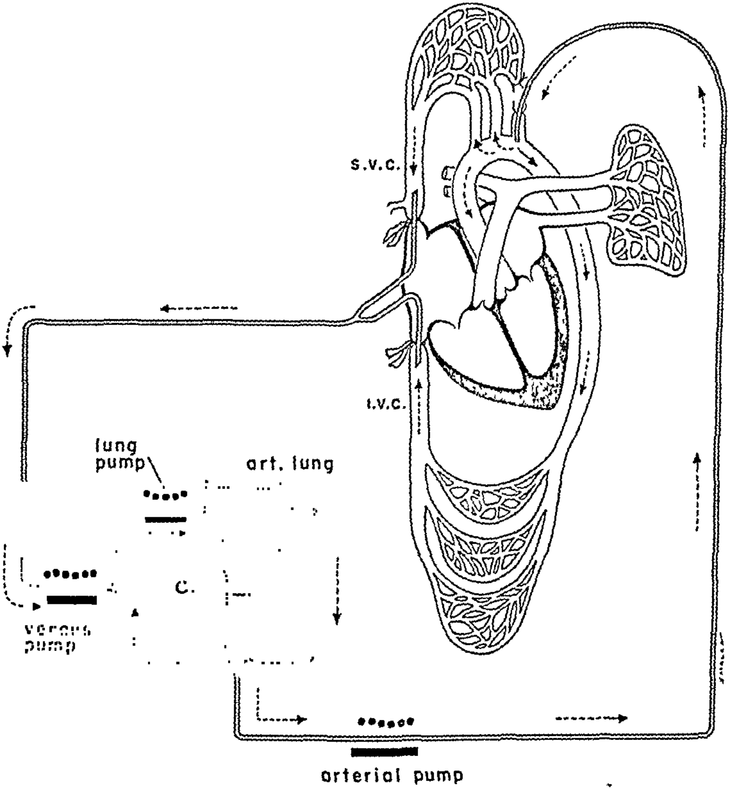

Fig. 1.—Diagram showing general principles of artificial maintenance of circulation. The blood is sucked out through two cannulae from the venae cavae. It is oxygenated and is pumped back into a branch of the aorta, in this case the left subclavian artery. The flow in the proximal part of the aorta is reversed and the coronary arteries having their openings above the aortic valve are provided with blood by the machine. When ligatures are tied around the roots of the venae cavae and the azygos vein, no blood will enter the heart, except that coming from the coronary sinus and the thebesian veins.

DESCRIPTION OF APPARATUS

The Artificial Lung.—After trying out various sizes, we selected the following type of polyethylene lung: 7-meter long strips of plastic-coated Fiberglas screen envelope two polyethylene tubes (Fig. 2). The polyetl has a lay-flat diameter of 2 inches and its wall-thickness is 1/1000 of an inch (1 mil). The two tubes have an oxygenating area of 14,000 sq. cm. On each side of the tubing are spacers to allow some distention of the tubing when the blood flows through it. The 7-meter long strips are wound around tin cans (10 cm. in diameter) and are provided with inlet and outlet tubing. The completed coil (Fig. 3) is placed in an ordinary transparent plastic bag, such as that used for vegetables. Warm (40° C.) oxygen is blown into the bottom part of the artificial lungs at a rate of 30 L. per minute (for eight lungs). A string

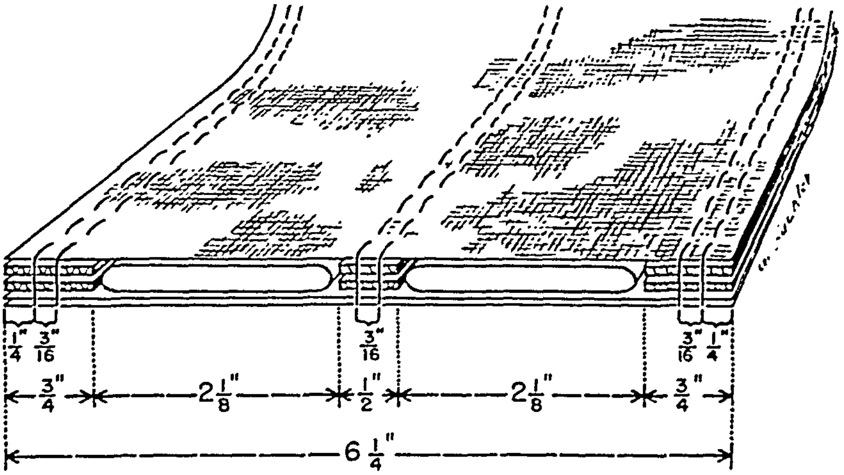

Fig. 2.—Cross section of membrane arrangement of the artificial lung. There are three layers of Fiberglas window screen, two tubes of polyethylene, and three pairs of spacers (to allow space for the tubes to become distended with blood). (Cross section through one coil of lung.)

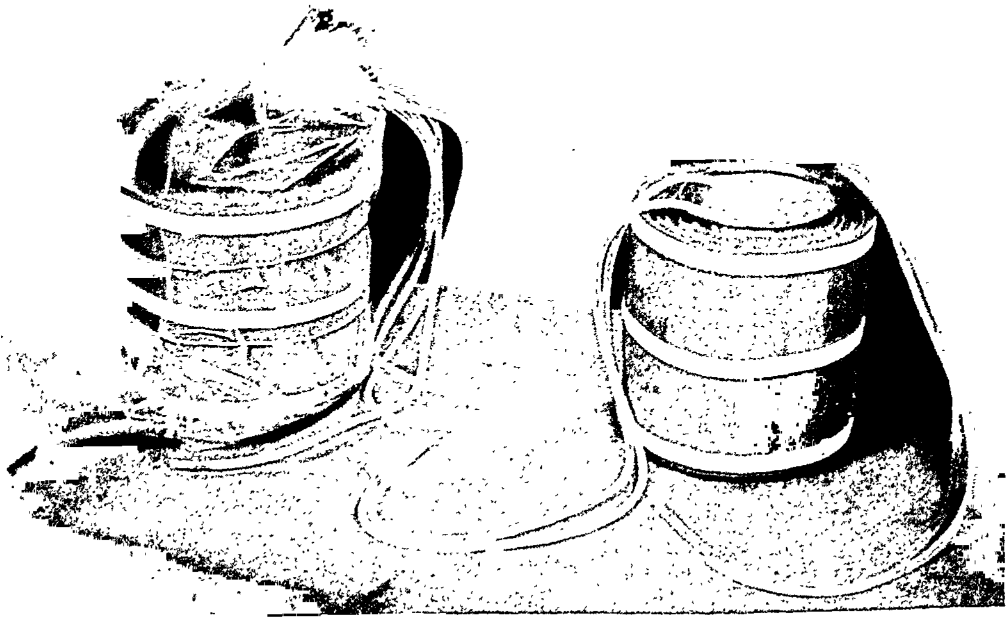

Fig. 3.—Artificial lung (right) and artificial lung in a plastic bag with tube for oxygen inlet at the bottom.

is tied around the top of the bag, just tightly enough so that oxygen flow will distend the bag, but loosely enough so that CO_2 and excess oxygen may escape through the top The lungs are prefabricated and sterilized with ethylene oxide by Baxter Laboratories* and can be kept sterile until needed Since the lung units are contained in transparent plastic bags, a blood leak can be seen The lungs are pretested at the factory, and in our experience only one in approximately 160 units had to be replaced because of a leak

The Pumps—We use commercially available finger pumps (Sigmamotor pumps†) The variable reduction transmissions in these pumps have been provided with dials for calibration

The Blood Circuit—In order to maintain a constant volume of blood in the oxygenator system we have adopted the third pump, as did Miller, Gibbon, and Gibbon [13]

The center section of Fig 4 outlines the lung circuit The first step is to recirculate blood through this circuit at a constant rate The lung pump is set to provide a flow slightly in excess of the maximal flow planned for the experiment Since blood flow through the lungs, resistance in them, and the volume of blood that accumulates in them are stable, the blood in the collecting manifold assumes a constant level Polyethylene is permeable to oxygen and CO_2 but is almost impermeable to water, so that there is no appreciable loss through evaporation Changes in volume of as little as 20 ml can be detected

To establish an artificial circulation, the arterial pump is set at a predetermined rate (usually 35 ml per kilogram of body weight per minute) and the venous pump is adjusted so that rates of inflow and outflow are identical, as judged from the level in the collecting manifold Since the volume of blood in the manifold and burette is large, accidental sudden reduction of inflow does not immediately deplete blood from the machine or result in an embolism When reduction of inflow does occur, it usually indicates that the dog has lost too much blood, so that caval flow is inadequate When this is the case, the dog is transfused from the transfusion burette Inadequate caval flow or obstruction of venous catheters may be recognized from an excessive negative pressure in the manometer attached to the bubble catcher in the venous line

Blood Used—Blood is drawn into siliconized blood transfusion bottles‡ containing 12 mg of heparin in 30 ml of diluent consisting of glucose, 2 5 per cent, and sodium chloride 0 45 per cent in water Each bottle receives 500 ml of blood Usually the blood is collected by puncture of the femoral artery

It is unnecessary to fill the machine with saline solution prior to use The equipment is assembled dry and it is directly primed with blood This avoids undesirable dilution of the donor blood with saline solution

The blood lost during operation is collected in a measuring cylinder that is coated with antifoam A so that the volume can be measured accurately without being obscured by foam An equivalent volume of blood is replaced and an additional 15 ml per kilogram of body weight is transfused during each run

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*Baxter Laboratories Morton Grove Illinois

†Sigmamotor Inc Middleport New York

‡Provided through the courtesy of Baxter Laboratories

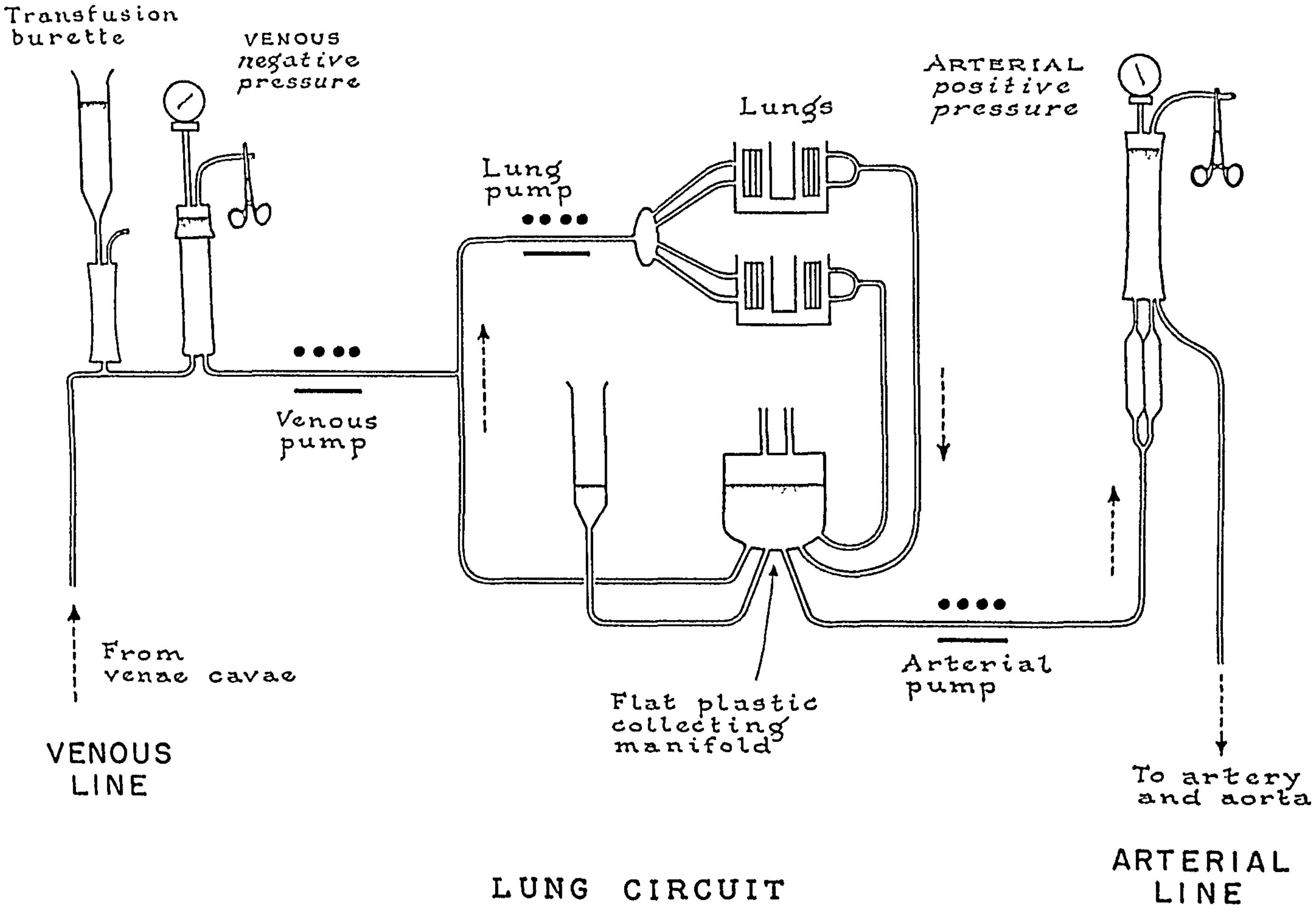

Fig. 4 —*For legend see opposite page.*

TECHNIQUE

In the first series of experiments a total of 140 dog operations were performed. The animals were prepared for surgery by antibiotics (penicillin 400,000 units, and streptomycin mg. 0.5) the day before. Five to 15 mg. of morphine was given preoperatively; endotracheal anesthesia was employed routinely using Pentothal sodium (1 per cent), succinylcholine supplement, and oxygen.

In the early experiments, testing of the oxygenator was the main purpose, and cannulations were performed from the neck. Later, to prepare for clinical use, intrathoracic cannulations were performed and every effort was made to simulate a human operation. The operative technique has been described by Lillehei and co-workers. The experimental operations were carried out in graded sequence (Table I). At first only caval occlusion was employed to test the oxygenator's ability to sustain the animal. The individual heart chambers were opened and closed; finally septal defects were created and closed. With each step there was an initial toll until experience and analysis of mistakes brought improvement.

TABLE I. RESULTS OF EXPERIMENTS WITH ARTIFICIAL HEART-LUNG MACHINE

LIGATURE OF VENAE CAVAE	RIGHT AURICLE OPENED	RIGHT VENTRICLE OPENED	INTERATRIAL SEPTAL DEFECT MADE AND CLOSED	INTERVENTRICULAR SEPTAL DEFECT MADE AND CLOSED
+	–	+	–	–
–*	–	–	–	+
+	+	–	–	+
+	+	–	–	+
+	+	–	+	+
+	+	+	–	–
	+	–*	–	+
	+	+	–	
	+	+	+	
			+	
			+	
			–	

Each + or – represents one dog.
+ = Dog survived and recovered completely.
– = Dog died within two days after the operation.
–* = Dog died more than one week after the operation.

RESULTS

Hemolysis.—Dog blood hemolyzes readily and hemolysis depends largely on the method of drawing blood. Good control of hemolysis was achieved by draw-

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g circuit. Blood coming from the venae cavae passes a bubble
manometer that indicates the degree of suction. The venous
the lung circuit. The arterial pump at right, pumps the
cuit through two filters, and a bubble catcher with a positive-
meter indicates the animal's blood pressure when the pump is
e sum of the animal's blood pressure, plus the pressure nec-
e in the arterial lines and cannulae while the pump is running.
lung circuit. The lung pump is set at a rate slightly higher
than the highest rate at which the arterial pump will work in the particular experiment. The
speed of the lung pump is not changed; with both venous and arterial pumps not running, an
equilibrium is established and the blood in the collecting
When the venous and arterial pumps are started and the le
of the machine are exactly alike.

ing blood into siliconized bottles* and by avoiding the formation of foam. Often 4 dogs were operated upon on the same day with the same blood in the machine; plasma hemoglobin in the machine taken at the beginning and end of the day showed an average increase of less than 20 mg. per hundred milliliters. Hemoglobinuria was never observed.

Oxygenation.—Determinations were initially made by the Van Slyke method; later the reflex oximeter of Brinkman† was used. One lung unit could oxygenate 75 ml. of blood per minute. Although oxygen saturation of venous blood is low when the small-flow principle is used, the oxygen saturation of the arterial blood still was over 90 per cent.

Acidosis (pH and CO_2).—The dogs were hyperventilated prior to the run on the heart-lung machine. CO_2 is effectively removed from circulating blood when recirculated in the oxygenator; although the CO_2 is reduced during recirculation of blood the pH is only slightly altered.

Metabolic acidosis must be expected during extracorporeal maintenance of circulation especially when the small-flow principle is followed. With sodium bicarbonate this acidosis can be corrected. A continuous drip of sodium bicarbonate (4.5 meq. per kilogram body weight made up to 100 ml. with 5 per cent fructose in water) is routinely administered during the run. A second dose is given during the first three hours postoperatively.

Temperature.—The oxygen going into the artificial lungs was heated to 40° C. but no other heating of the blood in the machine was provided. Consequently the dogs showed a fall in body temperature down to 34° C. during the run. This was corrected with a heating pad.

Disturbances in Clotting Mechanism.—The tendency of the animal to bleed has created difficulties for numerous investigators in this field. We also have lost a number of dogs from oozing or diffuse hemorrhage. In our recent experiments this complication has become rare. Heparin has been given: 0.8 mg. per kilogram of body weight to the dogs and 12 mg. per 500 ml. of blood. Heparin was neutralized with protamine sulfate (Upjohn), 25 mg. for small and 50 mg. for large dogs. This was followed by a continuous intravenous infusion of the same amount of protamine sulfate to prevent "heparin rebound."

Heparin Rebound.—This is a treacherous hemorrhagic phenomenon. When heparin is neutralized by protamine sulfate, the clotting time becomes normal in a matter of minutes. However, protamine sulfate seems to be eliminated from the blood stream before heparin is, thus leaving the heparin uncovered, as demonstrated by protamine titration.[14]

Thrombocytes.—Usually there is a transient fall in platelet counts, but it did not always occur. Within one hour the platelets were back to normal. The excellent clot retraction after administration of protamine sulfate also indicated normal platelet function.[12]

Prothrombin Times.—During treatment with the artificial heart-lung, prothrombin times changed no more than might be expected from hemodilution.[12]

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*Baxter Laboratories, Morton Grove, Illinois.

†Manufactured by Kipp in Delft, Holland.

This excludes damage to the early phases of the clotting mechanism in the two experiments studied.

Bleeding Time.—Stabbing with a hemolet into the undersurface of the dog's tongue at the end of the experiment and after administration of protamine sulfate did not reveal a prolongation of the bleeding time in any of the dogs in which it was tested.

The general conclusion in regard to clotting mechanism with this type of artificial heart-lung is that when heparin is adequately neutralized with protamine sulfate, only transient changes in the clotting mechanism occur. Within 15 minutes, the changes revert to normal. However, the use of old blood, large amounts of dextran or failure to clean parts of the machine affects the clotting mechanism disastrously.

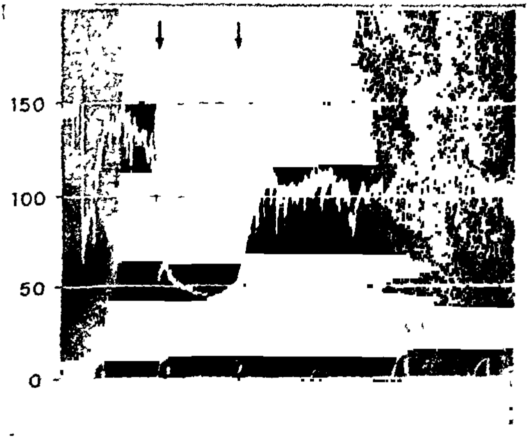

Fig. 5.—Experiment 55. Arterial blood pressure is indicated in mm. Hg. Time is indicated at the bottom in 10-minute intervals. At the first arrow, the artificial heart-lung is started and ties are put around the venae cavae. There is a sharp drop in arterial pressure and during the following minutes the right ventricle is opened. It is closed, and at the second arrow the ligatures are removed from the venae cavae. Blood pressure rises to about 100 mm. Hg within a few minutes.

Arterial Pressure.—Arterial pressure ranged from 25 to 50 mm. Hg during occlusion of the venae cavae and extracorporeal circulation, at 35 ml. per kilogram per minute; it returned to 100 mm. Hg within 5 minutes after release of the venae cavae in most successful experiments (Fig. 5).

Venous Blood Pressure.—The continuous observation of the venous blood pressure during the postoperative course has been very helpful in some cases when trouble arose. When both the venous pressure and the arterial pressure are low, the dogs should most likely be transfused. When the venous pressure is high while the arterial pressure is low, the cause of trouble should be other than loss of blood. It may be that the closure of the pericardium over the distended heart is too tight or it may be failure of the right heart.

"Second Run."—Thirteen dogs had low arterial blood pressure after the experiments, which evidently was due to cardiac failure. Extensive cutting into the interventricular septum probably was the cause. It has been possible to bring them into better condition by reconnecting them to the artificial heart-lung machine, leaving caval flow intact and using either the original cannulae or peripheral cannulation. In some dogs the artificial heart-lung machine was restarted two or three times. One dog was reconnected to the machine five hours after completion of the first experiment. It recovered.

Ventricular Fibrillation.—Ventricular fibrillation has occurred only three times in 125 experiments. Cardiac massage was not necessary during artificial maintenance of the circulation. The heart of one dog (No. 61) fibrillated after it had been closed and the machine had been stopped. The machine was started again for 8 minutes before a defibrillator was available. The heart of a second dog (No. 106) began to fibrillate 30 minutes after completion of the cardiac operation. The cannulae still were in place and he was reconnected to the machine. The heart of the third dog (No. 113) started to fibrillate when the chest was opened. The dog quickly was connected to the artificial heart-lung machine. Ventriculotomy was performed and the heart was defibrillated. All three hearts could be defibrillated, and normal cardiac action and blood pressure were restored, although later we lost the dogs. The last dog died two days after the operation from atelectasis. Fibrillation also has occurred, as will be discussed later, in dogs treated with elective potassium arrest; they recovered.

SUMMARY

Artificial heart-lung machines operate on the principle of taking blood from the occluded venae cavae, oxygenating it, and returning it to the aorta, so that the heart is by-passed. The artificial lungs described here oxygenate blood while it flows through polyethylene tubing. The lung unit discussed has an oxygenating area of 14,000 sq. cm., will oxygenate 75 ml. of blood per minute, and holds 500 ml. of blood. A recent refinement in manufacturing reduced the amount of blood needed to "prime" a unit to 270 ml. The lung units are disposable and simple enough to be mass-produced. As many as ten units may be used in parallel.

Experience in about 140 experiments in dogs is reviewed. Anesthesia was light and blood loss was fully replaced. Oxygenation was more than 90 per cent, even when the venous inflow was highly unsaturated. Hemolysis was negligible. Metabolic acidosis was countered, first by hyperventilation, and secondly by operative and postoperative infusions of sodium bicarbonate (4.5 meq. per kilogram of body weight each). Serum sodium increased within the normal range and serum potassium was not changed.

Bleeding problems were largely overcome. Transient disturbances of clotting mechanisms during the run, quickly reverted to normal. "Heparin rebound" was recognized by protamine titration. It was corrected, and later prevented by repeated doses or infusion of protamine sulfate.

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AN ARTIFICIAL LUNG DEPENDENT UPON DIFFUSION OF OXYGEN AND CARBON DIOXIDE THROUGH PLASTIC MEMBRANES

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A PRACTICAL blood oxygenator dependent upon the diffusion of gases through plastic membranes has been constructed and tested. It is the purpose of this paper not only to present this apparatus but to outline the physiologic concepts which entered into its development.

Denaturation of proteins is known to occur at a gas fluid interface,[1] and several years ago we demonstrated the formation of fibrin emboli by a bubbling type of oxygenator.[2] This resulted in brain damage and a high mortality in dogs perfused for more than one-half hour. Despite the outstanding successes of Lillehei and his co-workers using a bubbling device[3] and by Kirklin and his associates[4] using the Gibbon filming oxygenator, it was believed necessary to explore the possibilities of completely protecting blood from gaseous oxygen as is done in the naturally occurring gill and lung. Kolff and Blazer,[5] employing a modification of the Inouye artificial kidney,[6] have approached the problem from a similar viewpoint.

The experiments to be presented were divided into two parts. The first, to determine the permeability to oxygen and carbon dioxide of the available thin plastic films; a variety of these were tested in a diffusion chamber. The second dealt with the development and study of models to employ ethylcellulose and polyethylene membranes. From these studies have come an understanding of certain principles which govern the use of membranes for the oxygenation of flowing blood.

PERMEABILITY OF MEMBRANES TO BLOOD GASES

The rate of diffusion of oxygen and carbon dioxide through a variety of thin plastic membranes was measured in an apparatus containing a known quantity of venous blood on one side of the membrane and flowing oxygen on the other. Temperature was maintained at approximately 33° C., and the blood was kept well mixed by constant motion. Samples were taken every ten minutes for Van Slyke analysis,[7] or for determination of oxygen saturation by the Wood oximeter.[8] The rate of oxygen diffusion through the various membranes was compared by the formula:

$$\text{c.c. } O_2 \text{ diffusion/sq. m. surface area/min.} = \frac{\triangle O_2 \text{ content (vols. \%)} \times \text{volume blood} \times 100}{\text{surface area membrane (sq. cm.)} \times \triangle T \text{ (min.)}}.$$

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To assure the greatest attainable value for each membrane, measurements of ΔO_2 content were made during the steep part of each dissociation curve

In Table I are given data indicating that of the available films tested, ethylcellulose, one mil in thickness,[*] is superior to other materials in its oxygen permeability Polyethylene[†] and pure cellophane[‡] next in order of efficiency, compare favorably in certain respects with ethylcellulose Both ethylcellulose and polyethylene do not permit passage of electrolytes, although ethylcellulose permits water to evaporate at a very slow rate through itself Cellophane rapidly becomes coated with a dried deposit if fluid is not used on both sides This is a serious disadvantage for use in oxygenation in that the membrane becomes increasingly less permeable to gases Also considerable quantities of fluid may be lost by evaporation through this film Carbon dioxide was found to diffuse out of blood through all three films at a rate proportional to the oxygen uptake

TABLE I RATE OF OXYGEN DIFFUSION THROUGH PLASTIC MEMBRANES INTO VENOUS BLOOD

MEMBRANE	THICKNESS (INCHES)	C C O_2/SQ METER/MIN	
		VARIATION	MEAN
Ethylcellulose	001	7 6 13 1	11 4
	003	3 7 5 2	4 3
Polyethylene	0008	6 2 8 9	8 2
	001	6 3 8 1	7 6
Cellophane	001	7 0 7 7	7 4
	003	5 1 6 9	6 0
Polyvinylchloride	005	1 1 1 6	1 4
	010	0 6 0 72	0 7
Polystyrene	001	2 0 2 8	2 5
Mylar	0002	0 4 1 0	0 5
Chlorinated rubber	0004	0 1 0 6	0 4

Whereas, polyethylene is soft, pliable, and can be heat sealed, ethylcellulose is brittle, fairly easily torn, and cannot be sealed The former is available either as tubes or sheets, but the latter, being a cast membrane, is obtainable at present only in sheet form Both membranes of one mil thickness have tiny pinhole perforations, but there are many more at present in a given surface area of ethylcellulose than of polyethylene

DEVELOPMENT OF AN OXYGENATOR EMPLOYING ETHYLCELLULOSE MEMBRANES

A variety of small models were constructed to test the possibility of using ethylcellulose and polyethylene membranes to oxygenate flowing blood

In general, two methods for support of membranes were tried The first depended upon flowing blood along a screen with ethylcellulose membranes on either side held *in apposition by oxygen pressure outside The second depended* upon grooved surfaces to hold the membranes together Blood flowed between the membranes, while oxygen flowed in the grooves outside. Since sheet membrane was used, it was necessary to support all four edges by rubber gaskets to prevent leakage.

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[*] Made available through the kindness of the Plastics Technical Service The Dow Chemical Company Midland Mich

[†] Kindly supplied by the du Pont Company Wilmington Del and by the Dobeckmun Company Cleveland Ohio

[‡] Kindly supplied by the Visking Corporation Chicago Ill

The best of the latter type was developed into a multilayered apparatus with 6 square meters of surface area capable of supporting the whole circulation of small dogs up to two hours with complete recovery.

METHODS AND PROCEDURES

To evaluate the efficiency as well as the damage to blood done by each model of the oxygenator, the following general procedure has been followed. Venous blood from a heparinized dog was pumped into the apparatus between the layers of membrane and made to flow at a known rate. The oxygenated blood coming from the apparatus was returned under pressure to the carotid artery in such a fashion that the brain was perfused. This matter was established by the injection of radiopaque dye into the blood as it was perfused into the carotid artery. An x-ray made approximately five seconds later revealed the whole of the cerebral circulation to be outlined. These procedures were carried on for a minimum of one hour and usually longer. Sigmamotor pumps were used for convenience.

During each experiment the following observations were made: (1) oxygen and carbon dioxide contents of the venous and arterial blood as it entered and left the apparatus were determined by the method of Van Slyke; (2) *blood flow was accurately determined in cubic centimeter per minute by timed* collection of outflow in a reservoir, thus, it became possible to calculate exactly how much oxygen was passing into the venous blood per minute per square meter of surface area; (3) pressure of blood entering the apparatus was measured by a mercury manometer attached to the inflow line giving an index of resistance; (4) the electro-encephalogram was recorded on a Grass oscillograph during the perfusion; (5) clinical observations were made on the dog to determine evidence of brain damage.

RESULTS

Although considerable efficiency in oxygenation was obtained by causing blood to flow down a screen between layers of membrane held in close apposition by exterior oxygen pressure, imperfections in the membrane resulted in oxygen being forced into the film of blood. This caused bubble formation and immediately defeated the object of the membrane oxygenator.

Attention was devoted entirely, thereafter, to the development of oxygenators in which the oxygen pressure was maintained at a lower pressure outside the membrane than that of the blood inside. A variety of techniques for using wire screens or grooved surfaces for outside support of the membranes were tried. Screens tended to tear the membranes. Hard rubber ridges with 1/8-inch grooves between, when placed at 60 degrees or at 90 degrees to each other on the two sides of the membranes, resulted in a type of point suspension. If these were firmly held together, enough stretch took place in the membranes to allow the blood to flow between them. Oxygen was made to flow in the grooves outside the membranes.

Resistance within the oxygenator was found to be proportional to the distance blood was made to flow between the membranes and inversely proportional to the width of the film as it flowed across the oxygenating unit. To reduce the volume of blood trapped within each unit to a minimum, it was necessary to maintain as thin a film as possible with distributing channels down the sides of each unit of as small a cross section area as possible. It will be seen by the diagram in Fig. 1 that the side distributing channels are made by the bulging of the two membranes into the space between the rubber gaskets and the hard rubber diagonal ridges. Without increasing resistance materially, it was found that the flowing blood volume of each unit could be reduced to between 40 and 60 c.c.

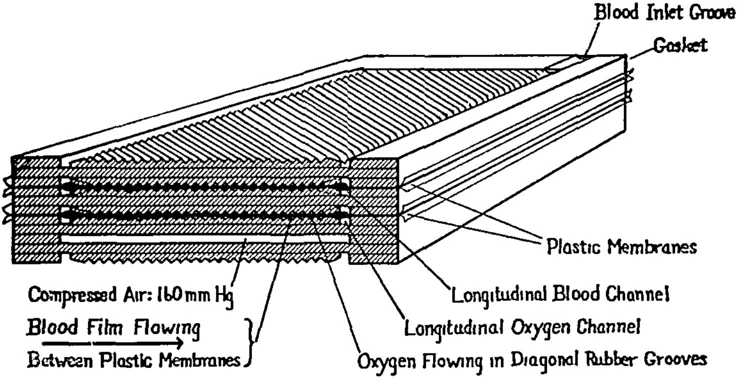
Blood Inlet Groove
Gasket
Plastic Membranes
Compressed Air: 160 mm Hg
Blood Film Flowing
Between Plastic Membranes
Longitudinal Blood Channel
Longitudinal Oxygen Channel
Oxygen Flowing in Diagonal Rubber Grooves

Fig. 1.—A cross section diagram of the multiple unit membrane oxygenator showing the course of blood and oxygen flow.

Ethylcellulose, one mil thick, in single units introduced on the average 8.6 c.c. of oxygen per square meter of surface area per minute into blood flowing at 100 c.c. per minute. This compares with the theoretical value of 11.4 obtained from the data in Table I. Through polyethylene (0.8 mil), oxygen diffused at a rate of 5 c.c. per sq. M. per minute which is approximately the same order of efficiency. If the flow was reduced to 50 c.c. per unit, the atrio-ventricular (A-V) difference of blood oxygen content did not double, and oxygen was transmitted less efficiently. In all probability this was due to a reduction of pumping pressure to about 85 mm. Hg which failed to open all the channels between the grooves.

Blood from single units being tested was pumped into the carotid arteries of dogs at a rate of 100 c.c. per minute for periods of one to four hours. There was no evidence of brain damage in these animals as indicated by a depression of electroencephalogram potential. They recovered without incident.

A MULTIPLE UNIT MEMBRANE OXYGENATOR

A multiunit apparatus is illustrated in Fig. 3. A variable number of units were employed depending upon the surface area desired. The separators which contain the grooved surfaces for support of the membranes are illustrated in Fig. 2. Each of these is constructed of hard rubber flooring material with 1/8-inch grooves between the ridges which are set at a 60 degree angle to each other and at a 30 degree angle to the crosswise direction of blood flow. This is mounted on 1/8-inch gum rubber and is surrounded by a 1/8-inch gum rubber gasket. The actual oxygenating surface upon which the membrane lies measures 10 by 42 inches. To avoid tearing the membranes, the grooved material is slightly beveled along the sides.

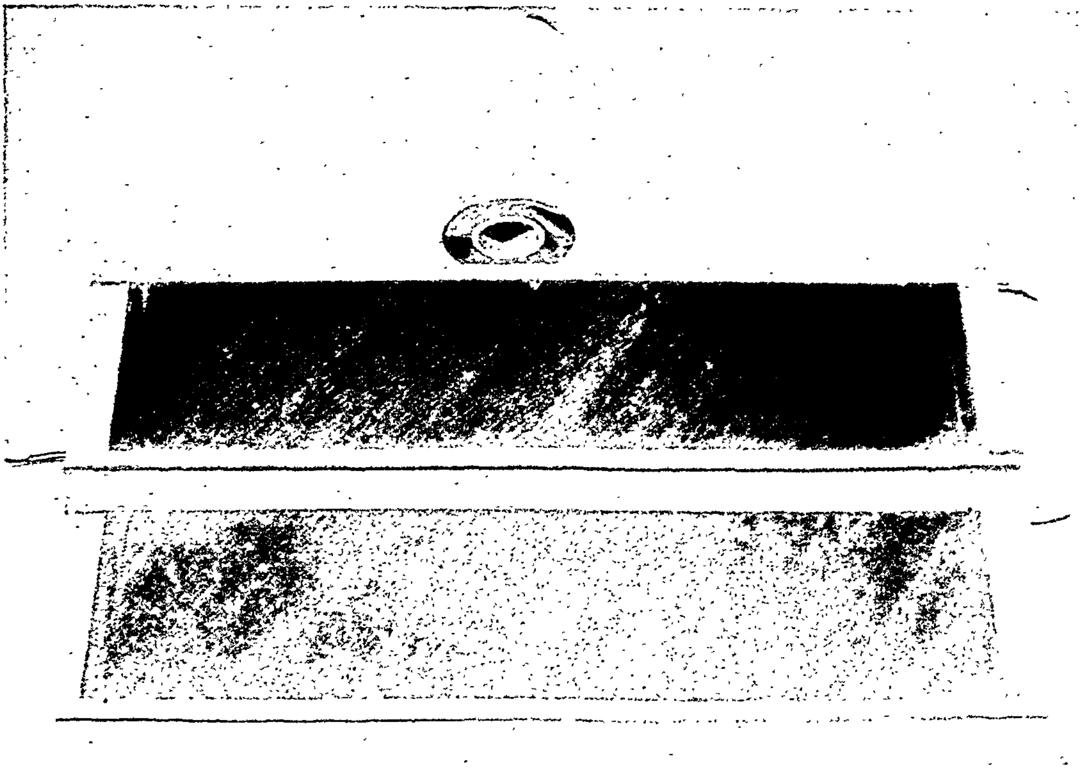

Fig. 2.—Illustration of the grooved separators for support of the membranes. The upper ·ator is inflatable. The flexible rubber tubes at the ends are for the introduction and exit ɔygen. Shown at the top is a roll of ethylcellulose, one mil thick.

The diagram in Fig. 1 illustrates the way in which the apparatus functions. ɔugh a manifold, venous blood enters each unit at one corner under pressure. ɔnnecting tube lying between the membranes held firmly in the blood inlet ıve permits the blood to enter the space between the membranes. Distending membranes slightly in the space between the gasket and the grooves, the d flows down the side. Being forced across the oxygenating area in a thin it collects on the opposite side in a similar longitudinal channel down ꞉h it flows to an outlet tube. This lies in a groove in the diagonally ɔsite corner to the inlet tube. The oxygenated blood is collected by a ifold system to be pumped back into the arterial circuit.

Pressure of the grooved surfaces against each other for support of the ed membranes is maintained by every fourth separator being inflated to ·essure of 160 mm. Hg. This is illustrated diagrammatically at the bottom of Fig. 1. In Fig 3, three tubes may be seen connected to these units at the middle of the near end. Stacked up units are held between heavy pieces of plastic at top and bottom. The whole apparatus being firmly clamped together with large "C" clamps. Oxygen enters each unit through a flexible rubber tube and flows down the longitudinal space between the gaskets and the grooves It then passes across through the grooves to the opposite longitudinal space to exit at the far corner. At the near corner of Fig. 3 is shown the oxygen distributing manifold connected to the oxygen inlet tubes. All exterior blood connections are made of plastic or gum rubber. Glass is almost entirely eliminated.

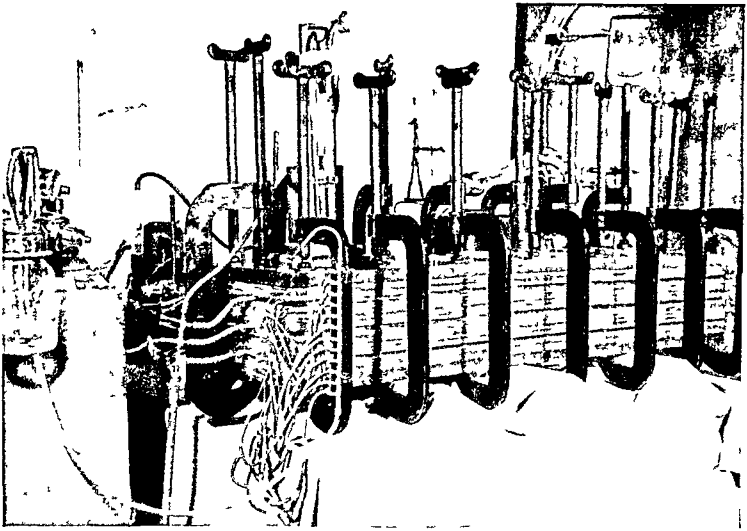

Fig 3.—The 12-unit membrane oxygenator in operation as seen from the end into which venous blood is being pumped

Using this device, it has been found that the greatest efficiency in oxygenation is produced if approximately 100 c c per minute of blood is pumped through each unit. This requires a pressure of approximately 120 mm. Hg Data on oxygen transmission to blood by the multiple-unit system are given in Table II.

Table II. Rate of Oxygen Diffusion Into Blood Flowing Through Oxygenator

MEMBRANE	INCHES	RATE OF FLOW (C C /SQ M./MIN.)	BLOOD TRAPPED (C C /SQ M /AREA)	MEAN BLOOD O_2 UPTAKE		
				A V DIFF	C C /SQ M./MIN.*	EFFICIENCY
Ethylcellulose	.001	200	80 120	4 1	8 4	74%
		100	70 100	6 2	6 2	54%
Polyethylene	.0008	200	120 160	2 7	5.4	71%

Note* Each unit of oxygenator has 0 5 square meter surface area.

Reduced flow rates resulted in less efficient oxygenation. Flow rates greater than 100 c.c. per minute through each unit caused bulging of the membranes and increased blood trapping within the apparatus. To maintain the optimum flow through the oxygenator a recirculation shunt was introduced to permit lower flows to the animal. Thus, with a 12-unit system functioning well, it was possible to pump 300 c.c. of blood per minute with an A-V difference of 16 volumes per cent, 600 c.c. with an A-V difference of 8 volumes per cent, or 1,200 c.c. with an A-V difference of 4 volumes per cent.

Ten dogs were subjected to partial perfusion through the carotid artery without brain damage. When total perfusions were undertaken with diversion of all circulation from the heart and lungs, it was found that cooling rapidly took place to levels between 28° and 32° C. Thereafter, a blood heater was incorporated into the arterial blood delivery line by which body temperature was easily controlled.

A consecutive series of 10 dogs weighing up to 10 Kg. were subjected to total perfusions for periods over thirty minutes. In two instances this was carried on successfully for two hours, and in two others, for one hour. One dog died ten hours postoperatively of continued bleeding. In none of these was there evidence of cerebral damage.

Ethylcellulose, one mil thick, was used for the experiments described above. The chief problem encountered in this series was leakage of blood through very small holes in the membranes into the oxygen grooves rendering the apparatus less effective as time of perfusion progressed. Another two perfusions were carried out using polyethylene film 0.8 mil in thickness. Leakage with this material was slight but oxygen transmission was less satisfactory.

DISCUSSION

These experiments demonstrate that it is possible to oxygenate blood satisfactorily through thin plastic membranes provided that the surface is large enough to transmit adequate quantities of oxygen to sustain life without undue blood trapping or resistance to flow. Data in Table I indicate that definite limitations of oxygen transmission are imposed by the characteristics of the membrane used. Efficient use of the membrane surfaces was obtained by causing blood to flow in a thin film between them without pooling, stasis, or channelling. This required even support of the membranes from the outside. Resistance was reduced by a short but effective exposure of the blood to the membrane area as is done in the capillaries of the lung. To avoid undue trapping of blood in the apparatus, distribution to the film areas was accomplished in the smallest channels consistent with reasonably low resistance to flow. Finally, oxygen was made to flow freely over the outside surface of the membrane to avoid channelling or stoppage of oxygen flow. This corresponds to the mixing problems encountered in the lung.

The lack of brain injury in animals, perfused so that the majority of the blood from the oxygenator was circulated through the cerebral vessels, suggests that embolus formation and other blood damage was minimal.

The multiple unit system capable of expansion to furnish an adequate oxygen supply for a given organism has proved capable of sustaining life for prolonged periods when the heart and lungs are rendered inoperative The fact that each unit can transmit 4 c c of oxygen per minute to flowing blood, yet only contains 40 to 50 c c of blood when in operation, makes it a reasonably practical piece of equipment for clinical use It should be emphasized that this apparatus is presented not as a finished article but as a functioning oxygenator which illustrates the principles which govern the use of membranes in the artificial oxygenation of blood

SUMMARY

1 Diffusion tests suggest that of the available thin plastic membranes, ethylcellulose permits the greatest passage of oxygen and carbon dioxide Polyethylene is approximately three fifths as effective

2 Efficient oxygenation of blood with membranes can be accomplished with a surface area adequate to transmit the necessary quantity of oxygen provided resistance to blood flow and trapping of blood are reduced to a minimum

3 A multilayered system has been constructed capable of oxygenating blood adequately for support of the circulation of dogs when the heart and lung were not functioning Nine of 10 dogs so treated survived

The authors wish to express their appreciation to Mr Howard Peacock for his interest and help in this project

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EXTRACORPOREAL CIRCULATION FOR OPEN HEART SURGERY

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THE initial studies by Gibbon in 1937[5, 6] concerning the possibility of extracorporeal perfusion for open heart surgery under direct vision have led to intensive investigations in many laboratories. Since the first application of this technique in human subjects by the Minnesota group in 1951,[3] this approach has become more widely adopted. The definition of the "azygos flow principle" (or perfusions of less than full cardiac output), by Cohen in 1954,[2] provided a factor which laid the foundation for controlled cross circulation, first successfully employed in human cardiac surgery by Lillehei and his associates in 1954.[11, 19] This method of perfusion demonstrated clearly that corrective open heart surgery was possible. Efforts were then accentuated to bypass the heart temporarily by completely artificial means, thereby obviating the need for a human donor. Perfusions were next accomplished by means of a reservoir of arterialized blood,[18] and oxygenation by means of a dog lung,[12] followed shortly by wider scale application of the Gibbon type machine.[4, 9, 10] Still the need was apparent for the development of a less complex apparatus capable of pumping and oxygenating the blood for the time necessary for the correction of intracardiac abnormalities. With this in mind, the technique to be described was developed.

Since this work was inaugurated, Lillehei has used the DeWall artificial lung with repeated success, again demonstrating the reality of satisfactory extracorporeal circulation to permit intracardiac surgery under direct vision.[14]

METHOD

A. *The Artificial Heart-Lung Apparatus.*—

1. The pump used is that developed for the cross circulation procedure of Lillehei.* It consists of a single explosion-proof electric motor (⅓ horsepower) which drives two finger pumps regulated by separate transmissions. By individual adjustment of vernier control, the flow rates of the two pumps can be balanced.[13] We have routinely employed Latex tubing, ½ inch I.D., to serve as the "ventricle" in the pumping chamber.

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*By Sigmamotor, Inc., Middleport, N. Y.

2. The oxygenator is depicted in Fig 1 It consists of two concentric Lucite cylinders The inner cylinder constitutes the foaming chamber and measures 1¼ inches I.D. by 14 inches in height The outer chamber is 4¼ inches in diameter and 17 inches in height Another antifoamed-screen rests below the top of the center column to reduce secondary splash effects It is sloped on the bottom to provide for dependent drainage The outer chamber serves as a reservoir for the arterialized blood and as a bubble trap. This artificial lung represents a modification of the bubble-type apparatus reported by other investigators.[1, 7, 8, 15, 16]

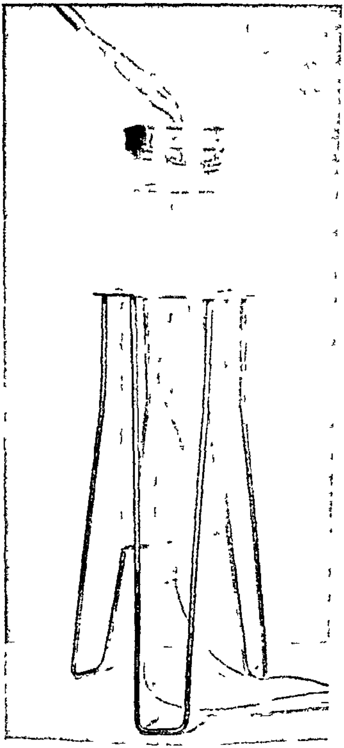

Fig 1—This is a photograph of the artificial lung used in this study. Note the oxygen catheters leading into the inner foaming chamber the outer receiving chamber, and the metal mesh at the top of the "lung"

Venous blood is introduced into the "lung" at the bottom of the inner foaming chamber. Here the blood is exposed to a gas mixture of 95 per cent oxygen and 5 per cent carbon dioxide conveyed from the gas tank via two 14 Fr. oxygen catheters introduced from the top. Bubbles formed as a result of this interaction rise to the top of the foaming chamber and spill into the outer receiving chamber which has been coated with Antifoam.* A fine mesh stainless steel screen and a metal sponge,† each coated with Antifoam, are placed just above the top of the foaming chamber in the event the column of bubbles should rise to this height. When the bubbles contact the Antifoam, decreased surface tension causes the bubbles to burst. Gas in the center of the bubble which has equilibrated with the excess carbon dioxide in the venous blood then escapes through the top of the "lung." The blood which surrounded the bubble gravitates to the bottom of the reservoir. The bubble-free oxygenated blood is then ready to be pumped back into the arterial tree of the patient. Diagrammatic scheme of the circuit is shown in Fig. 2.

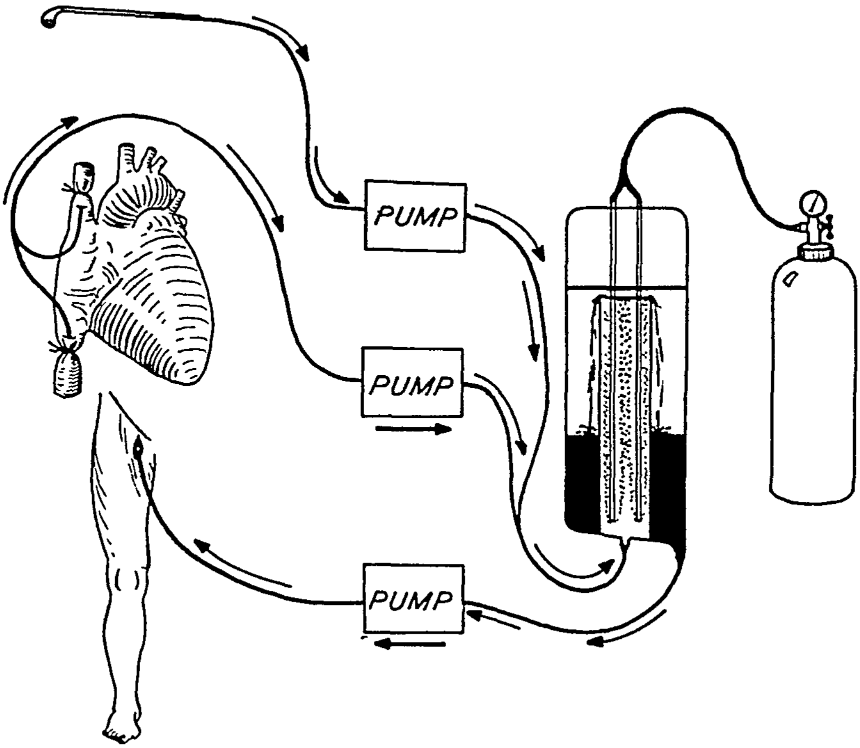

Fig. 2.—This is a schematic representation of the extracorporeal circulation employed. Blood from the vena cava and from the cardiotomy suction is pumped into the foaming chamber where it is mixed with 95 per cent oxygen and 5 per cent carbon dioxide. The reservoir blood is returned to the arterial system.

The flow rate of gas into the artificial lung has been one liter per 100 ml. blood flow per minute. The blood from the first 5 dogs was exposed to 100 per cent oxygen, resulting in excessive removal of carbon dioxide from the blood and respiratory alkalosis. Therefore, subsequent perfusions were carried out with 95 per cent oxygen and 5 per cent carbon dioxide. To prevent the possibility of air embolism, a sizeable volume of blood, at least 1,000 ml., and preferably 1,500 ml., must be maintained in the reservoir at all times.

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*Dow-Corning Co., Midland, Michigan.

†Metal Textile Corporation, Roselle, New Jersey.

The artificial oxygenator and the supporting brass ring stand are sterilized by autoclaving. Careful positioning is necessary during autoclaving because of the tendency of the Lucite to melt and become distorted.

3. The tubing used is polyvinyl, a transparent plastic material, which is also sterilized by autoclaving. On the venous side of the circuit, the tubing measures $\frac{1}{4}$ inch I.D. and on the arterial side, $\frac{3}{16}$ inch I.D. Catheters for withdrawing and returning the blood likewise are of flexible plastic which are autoclaved after being placed in open Pyrex tubing to prevent distortion. Sizes of the catheters range from 10 Fr. to 22 Fr., depending on the diameter of the vessel to be cannulated.

4. Connectors and adaptors are of stainless steel with smooth tapered interior surfaces.

5. An accessory Sigmamotor pump is employed to return the coronary sinus and Thebesian venous blood encountered during the open cardiotomy. This is returned to the venous side of the apparatus, oxygenated, and then recirculated as shown in Fig. 2.

B. *Experimental Procedure.*—

Seventeen dogs ranging in weight from 12 Kg. to 25 Kg. were operated upon with a view toward survival. Perfusion was accomplished by aspirating blood through catheters placed in the superior vena cava via the azygos vein, and the inferior vena cava, reached by way of the right auricular appendage. Blood was returned into the abdominl aorta by introducing a plastic tube into the superficial femoral artery. Perfusion flow rates were between 20 to 35 ml. per Kg. per minute.

Intravenous Nembutal or Pentothal sodium was used for anesthesia. Thoracotomy was performed through the right fifth intercostal space or anterior bilateral intercostal incision transecting the sternum. Positive pressure respiration was used in the open chest surgery.*

After cardiac by-pass was instituted, a long incision was made into the chamber of the right ventricle or the right atrium or both, which incisions were held open up to thirty minutes. The incisions in the heart were then repaired with running 3-0 silk sutures. During the by-pass of the heart and lungs, the positive pressure respirator was disconnected and the lungs allowed to deflate.

The animals were heparinized (1.5 mg. per Kg.). Donor blood sufficient to prime the pump and reservoir was collected, using ether for donor anesthesia and 20 mg. heparin per 500 ml. for anticoagulation. Protamine sulfate was used to counteract the heparin effect at the conclusion of the perfusion. Dosage employed was equivalent to that of the heparin previously administered.

Catheter drainage of the pleural cavity was maintained for two to four hours postoperatively until the dogs had recovered from the anesthesia.

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*The authors gratefully acknowledge the 1
the experimental and clinical procedures reporte

RESULTS

A. *Mortality Figures.*—

Fourteen of the dogs thus treated still survive, ranging now from ten to three months following the operation. One dog succumbed on the fifth postoperative day of canine distemper, a condition evident preoperatively and confirmed by microscopic study. One of the initial dogs died of generalized wound oozing.

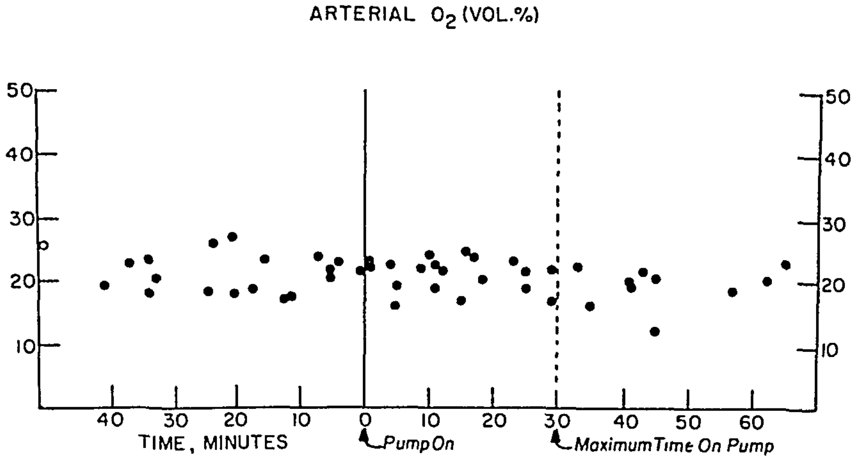

Fig. 3.—This figure plots the values for arterial oxygen saturation, reported as volumes per cent at times indicated in minutes before, during, and after cardiac by-pass. It is evident that adequate oxygen saturation was maintained throughout the experiments.

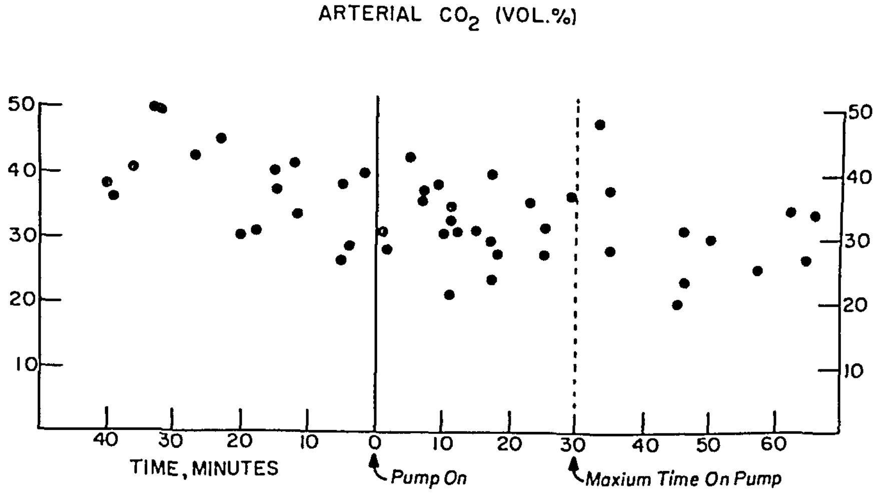

Fig. 4.—The values for carbon dioxide concentrations are recorded as volumes per cent at various times during the experiment. Note that the points for values obtained during the cardiac by-pass fall within the range for values determined before and after the by-pass.

At that time, the artificial lung was made of glass. No similar complication has been observed since changing to Lucite. The third fatality was due to an inadvertent overdose of Nembutal.

B. *Physiologic Data.*—

1. Arterial oxygenation was monitored by a direct recording oximeter with samples obtained from an indwelling catheter in the carotid artery. Frequent

samples were analyzed by the technique of Van Slyke. Values obtained before, during, and after the period of cardiac by-pass are indicated in Fig. 3. This was shown to represent virtually 100 per cent oxygen saturation of all samples.

2. The arterial carbon dioxide concentration, determined by the Van Slyke technique, was measured at intervals throughout the procedure. The data obtained are plotted on Fig. 4.

The mean values for oxygen and carbon dioxide concentrations are shown in Fig. 5, indicating maintenance of physiologic levels of gas concentrations during extracorporeal circulation.

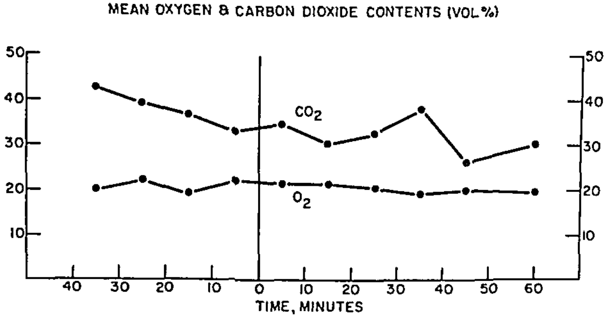

Fig 5.—Mean values for oxygen and carbon dioxide levels are plotted above

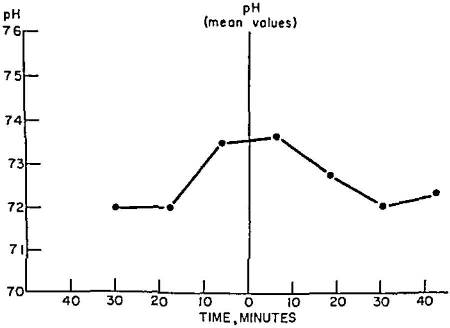

Fig 6.—The mean values for pH show essentially the same variation during the period of the perfusion as in the pre- and postperfusion intervals of open chest surgery.

3. Arterial pH determinations are depicted in Fig. 6.

4. Plasma hemoglobin values consistently rose to a level of 120 mg. per cent at the conclusion of thirty minutes' perfusion.

5. Electrocardiographic patterns were monitored throughout the experiments and have shown the expected transient injury patterns and firing of ectopic foci associated with the intracardiac manipulations. lo[illegible]as

manipulation of the interventricular septum was avoided, no serious arrhythmias were encountered. The body temperature was not lowered in the belief that the heart at normal temperatures is less likely to develop dysrhythmias. Pulse pressure contours were recorded using an optimally damped strain gauge galvanometer system. The records indicated that the arterial systolic pressure was maintained in the range of 70 to 90 mm. Hg during the period of perfusion. None of the dogs has exhibited any discernible renal, neurological, or other sequelae. The 14 survivors are evidently normal in every respect.

DISCUSSION

From the foregoing data, it is evident that by the use of this relatively simple oxygenator, flow rates ranging from 280 ml. per minute to 780 ml. per minute can be handled in dogs, maintaining arterial oxygen, carbon dioxide, and pH values within the range of variation observed before and after the perfusion. By this technique, it has been possible to open the right ventricle, right atrium, or both chambers for periods up to thirty minutes, with a regular incidence of permanent survival. The thirty-minute period was chosen for study inasmuch as most intracardiac defects can comfortably be handled in that time.[13]

This method of cardiac by-pass differs essentially from others in the simplicity and effectiveness of the gas exchange chamber. Even larger flow rates (up to 4,500 ml. per min.) are possible by merely modifying the pump and increasing the height of the foaming and receiving chambers of the oxygenator. These revisions are currently being evaluated in this laboratory.

CLINICAL APPLICATIONS

The use of this apparatus for human intracardiac surgery will be reported in detail elsewhere[17] but may briefly be cited here. To date, 5 patients have had direct-vision open heart surgery during perfusion by this means. The results are summarized in Table I.

TABLE I. HUMAN INTRACARDIAC SURGERY WITH BY-PASS TECHNIQUE

AGE	WEIGHT (KG.)	DIAGNOSIS	PROCEDURE	MINUTES ON BY-PASS	OUTCOME
39	57	Atrial septal defects (2)	Direct suture	7	Survived*
8	28	Atrial septal defect with pulmonary hypertension	Direct suture	8	Survived
31	59	Common atrium	Direct suture	20	Survived
4	13	Pulmonic stenosis	Open valvuloplasty	15	Survived
7	16	Tetralogy of Fallot	Open valvuloplasty and suture of vent. septal defect	24	Died†

*Operation performed Nov. 9, 1955.
†Died 2½ days postoperatively—renal failure.

During each of these operations, the oxygen saturation was assessed by means of the ear oximeter, and found to be maintained at normal levels as long as the flow rate of gas was approximately one liter for each 100 ml flow of blood per minute Maximum flow in human perfusions has been 2,100 ml per minute

CONCLUSIONS

Extracorporeal circulation for open heart surgery has been accomplished by means of a simplified plastic bubble type artificial lung in conjunction with the Sigmamotor cross circulation pump All of the apparatus which comes in contact with blood is autoclaved Fourteen of 17 dogs subjected to open cardiotomy for periods up to thirty minutes still survive Analysis of blood oxygen, carbon dioxide, pH, plasma hemoglobin electrocardiographic and pulse pressure data indicates that physiologic ranges are preserved Flow rates up to 2,100 ml per minute have been used Brief reference has been made to the use of the apparatus in 5 patients for corrective open heart surgery

ADDENDUM

Since this paper has been presented, the apparatus has been somewhat revised A new Sigmamotor pump has been employed which uses a ¾ inch I D rubber tubing in the pumping chamber, thereby increasing the pumping capacity to 4,800 ml per minute

The oxygenating chamber has been enlarged to 34 inches in height and is made of glass All surfaces are carefully siliconed No undesirable sequellae have been observed from this change This eliminates the problem of distortion of the chamber associated with autoclaving

Hemolysis has been reduced by minimizing the turbulence in the bubbling column This has been accomplished by introducing the stream of gas into the bottom of the bubbling column through a thin rubber diaphragm perforated with many tiny holes

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A MECHANICAL PUMP OXYGENATOR FOR DIRECT VISION REPAIR OF ATRIAL SEPTAL DEFECTS

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THE desire for a direct vision surgical approach to intracardiac defects has stimulated the development of mechanical pump oxygenators. The various extracorporeal circuits now available have been designed to deliver pulsatile or continuous flows of blood oxygenated by filming,[1, 2] bubbling,[3] dialysis,[4] and passage through the isolated lung.[5] Failure of many of these by-pass systems to gain wider clinical application has been due to the potential hazards associated with the use of them. Air embolism of extra- and intracardiac origin and hemorrhage constitute the principal dangers to the recipient.

The extracorporeal circuit described in this report, a modification of an earlier model,[6] has been used extensively in experimental procedures to investigate these problems.[8] Additional studies were conducted to re-define the acute metabolic changes in animals undergoing total by-pass since the physiologic alterations suggested by previous results were not in accord with our current concepts. The material in this presentation deals with our experience in the creation and repair of interatrial septal defects in 31 dogs and the successful application of the pump oxygenator to a clinical case.

METHOD

Mongrel dogs weighing 8 to 35 Kg. were anesthetized with intravenous pentobarbital sodium, intubated, and placed on a mechanical respirator. Surgery was performed aseptically. The chest was entered through the bed of the right fifth rib (first 12 dogs) or transsternally in the fourth intercostal space (19 dogs). The azygos vein was ligated in continuity. The left subclavian artery was exposed and divided distally. After the pericardium had been widely incised, the inferior and superior venae cavae were isolated extrapericardially and surrounded by sling ligatures. Hemostasis was obtained by the use of electrocautery. Heparin (Connaught Laboratories), 2.5 mg. per kilogram, was administered intravenously at the completion of all dissections.

During this initial preparation, the extracorporeal circuit, which has been reported previously in detail[7] was assembled (Fig. 1). The flowmeter was

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an electromagnetically recording rotameter.[10] The rate of venous outflow was recorded on a Sanborn Poly-Viso. The venous blood was delivered to rubber jets placed near the axis of the oxygenator and filmed on four rotating discs. Venous drainage was assisted by a siphon effect equal to the vertical distance between the venae cavae and the openings of the jets (*A* to *B* in Fig. 1); this measured 40 cm. in most animals. The oxygenator tank was continuously flushed by 100 per cent oxygen. The bubble trap contained stainless steel scouring sponge, coated with Antifoam-A (Dow Corning), within the inner cylinder.[3] It served effectively both as a bubble remover and as a filter for fibrin. In no instance in these experiments was the extracorporeal origin of air embolism implicated. The modified Dale-Schuster pumps[11] were activated by compressed air regulated by solenoid valves. A pulsatile stream, 14 to 17 ml. per stroke, was delivered to the systemic circulation. Filling of

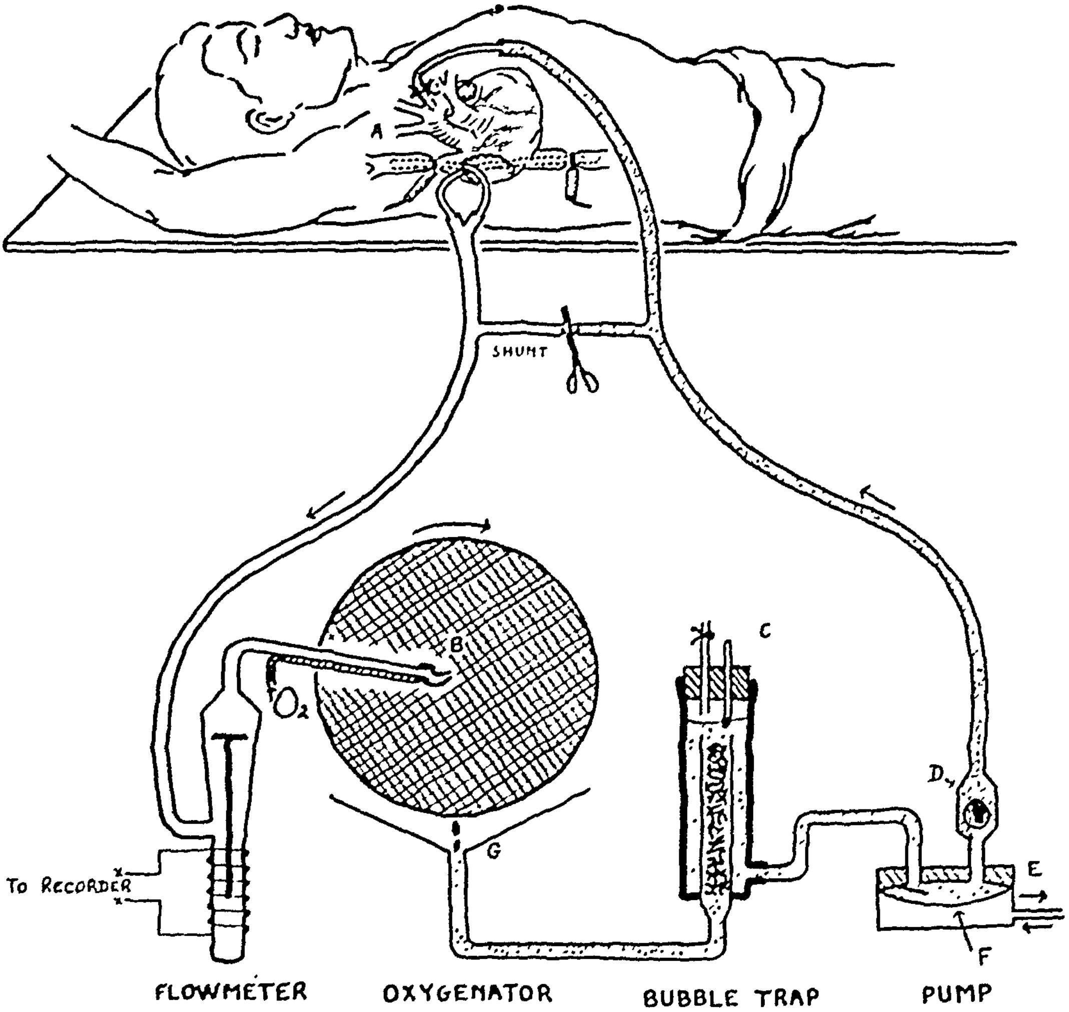

Fig. 1.—Diagram of pump-oxygenator assembly for total body perfusion. *A*, Catheters in place in the left subclavian artery and in the superior and inferior venae cavae. *B*, Rubber jets film the blood on rotating discs above oxygen inlet. C, Outlet for removing air accumulated in bubble trap and thermometer for recording blood temperature. *D*, Nylon shuttle valve prevents regurgitation into pump. *E*, Compressed air from solenoids motivates diaphragm, *F*, of pump which is filled by hydrostatic pressure of blood column, *G*.

the pumps was dependent upon the displacement of rubber diaphragms by the hydrostatic pressure of the column of blood (*G* in Fig. 1) from the oxygenator. "Gravity filling" eliminated the negative phase in the pumping cycle and prevented air above the blood level in the oxygenator from entering the arterial side of the extracorporeal circuit. The pumps were therefore self-regulatory, accelerating when the influx of blood was increased and slowing as the flow decreased. This minimized gross fluctuations in the holdup volume.[12] For any single perfusion, the stroke output was fixed and the minute volume varied directly as the rate. In anticipation of high flows in large subjects (over 40 Kg.), the capacity of the system was increased by incorporating two bubble traps and using two larger pumps with stroke outputs of 85 ml. The principal limiting factor in achieving these high flows was the caliber of the cannula capable of being threaded into the artery of the recipient.

Freshly drawn, unmatched blood, heparinized with 30 mg. per 1,000 ml., was obtained from donor dogs for priming the extracorporeal circuit (1,100 ml.) and replacement of operative losses. The femoral vein and artery were used for drainage and return of blood in the first 9 animals. In subsequent procedures, the left subclavian artery was cannulated with a plastic catheter (OD – 14 Fr.).* Similar catheters were placed in the superior and inferior venae cavae through the right auricular appendage with the tips positioned distal to the sling ligatures. A shunt (see Fig. 1) connecting the efferent and afferent limbs of the extracorporeal circuit provided a method for removing *residual air bubbles from the system before perfusion.*

Blood pressure in the femoral artery and venous pressure in the external jugular vein were monitored by Statham strain gauges recording on a Sanborn Poly-Viso. The electrocardiogram was observed on an oscilloscope throughout the procedure. Prior to and again at the end of the by-pass, blood samples were obtained for determinations of the pH, CO_2, oxygen content of arterial and venous blood, hemoglobin, hematocrit, free plasma hemoglobin,[13] total protein, albumin, fibrinogen, pyruvic acid, plasma chloride, and protamine titre.[14] The analytical methods used for blood chemistry have been recorded elsewhere.[9]

The animal was placed on partial perfusion by occluding the shunt and opening the cannulae (see Fig. 1). Total perfusion was obtained by tightening the sling ligatures about the venae cavae. The heart was allowed to empty for 15 seconds. A 5 centimeter incision was made in the wall of the right atrium from the junction with the inferior vena cava parallel to the atrioventricular groove (Fig. 2). The coronary sinus, tricuspid valve, and crista terminalis were identified. A 2 to 2.5 centimeter incision was made in the interatrial septum. This was confirmed by the appearance of arterialized blood. Rapid suction was used to remove blood draining into the operative site from the left atrium, coronary sinus, and anterior cardiac veins. Frequently, this was returned to the extracorporeal circuit as losses accumulated. The septal incision was closed with interrupted silk sutures and the right atrial wall with a continuous silk suture.

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*A beveled curved metal cannula was used for arterial cannulation in the first 17 animals.

Throughout the by-pass, efforts were made to maintain the blood volume at pre-perfusion levels. As they occurred, suction and other operative losses were corrected via the arterial side of the circuit by direct replacement into the oxygenator. In the presence of hypervolemia, a measured quantity of blood was permitted to drain back into the oxygenator. Size of the heart and venous and arterial pressures were guides to the restoration of a normal circulating volume. Protamine (diluted twentyfold with five per cent glucose in distilled water) was administered intravenously over a 15-minute period following decannulation. The dose was dictated by the protamine titer obtained at the end of perfusion. Blood losses incurred subsequent to this stage in the procedure were replaced by direct transfusions of fresh whole blood.

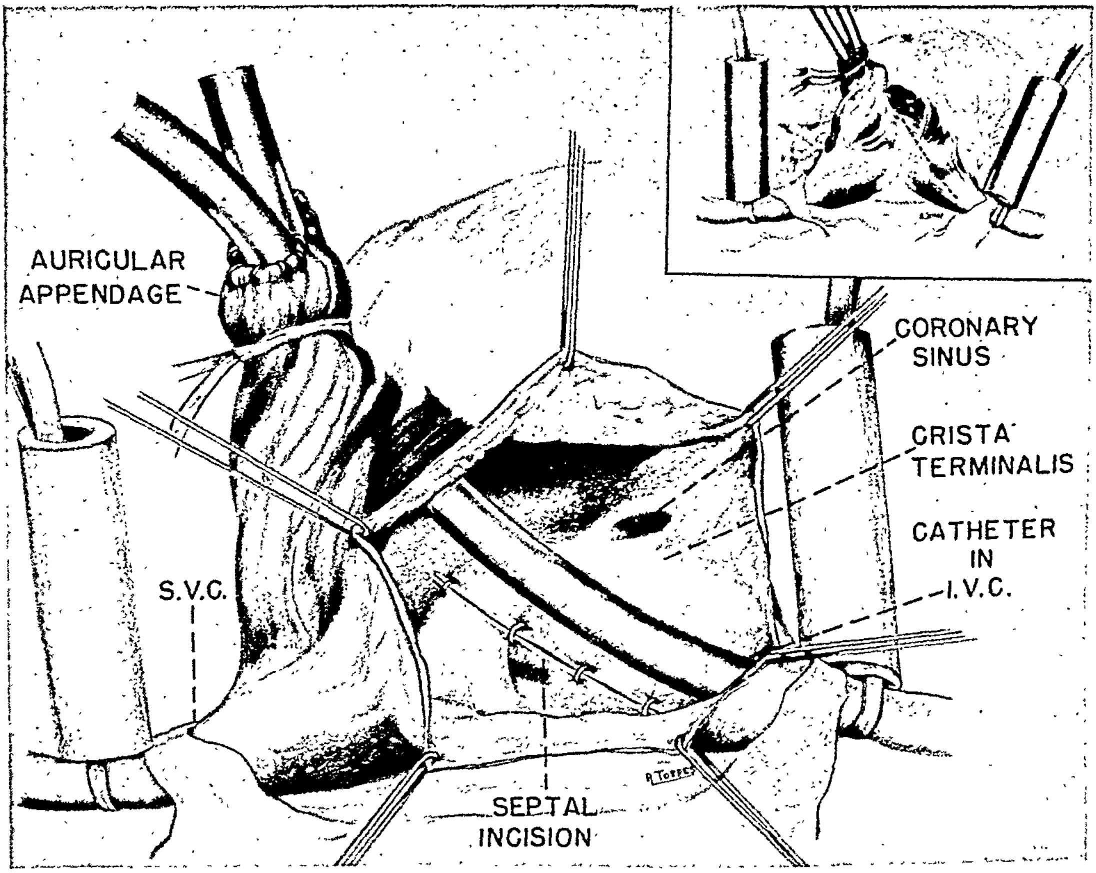

Fig. 2.—Exposure of the interatrial septum through the right atrium. The catheter can be displaced to facilitate the approach to the septum. *Inset;* Type of incision employed in atriotomy.

Large-bore thoracostomy tubes were placed in both pleural cavities and connected to waterseals. The pericardium was loosely approximated and the chest wound closed in layers. Postoperatively, the animals were observed with regard to adequacy of ventilation, chest drainage, body weight, blood pressure, rectal temperature, and reaction from anesthesia. To correct the mild hypothermia produced during the by-pass, the animals were rewarmed on blankets.* Vigorous efforts were made to evacuate blood and air from the pleural cavity and encourage lung expansion Bleeding from the chest was promptly corrected with whole blood transfusions At regular intervals, fractional protamine titrations were obtained and appropriate doses of protamine administered until the clotting time returned to normal Persistent chest drainage in the presence of a normal clotting time and absence of circulating heparin was an indication for re-exploration in one animal in which bleeding from the right atrial appendage was corrected A normal circulating volume at the end of a procedure was reflected in a favorable comparison of pre and post operative body weights

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*Therm-O-Rite Products Corp., Buffalo, N. Y.

Three techniques were employed to prevent embolization of air through the incised interatrial septum In 13 dogs a multiperforated vent was placed into the left ventricle through a stab wound in the avascular portion of the apex as recommended by Miller and his co-workers[15] Aspirated blood and air under a negative pressure of –10 to –20 cm of water, were returned directly to the oxygenator In 12 dogs, an attempt was made by positioning the animals to preserve a continuous "lake" of blood or saline solution over the incised septum Five degrees of Trendelenburg position were used to prevent air emboli from reaching the brain[16] In 6 animals, ventricular fibrillation was induced with a shock of a 6 volt 60 cycle alternating current through two closely spaced electrodes applied to the ventricular epicardium[1] Defibrillation was accomplished while the animal was on total perfusion with a counter shock of 125 volts for about 0 1 second

RESULTS

Thirty one dogs were perfused for periods of 17 to 63 minutes in which time an interatrial septal defect was created and repaired Rectal temperatures fell progressively during the by pass The average decrease was 5 5° C and varied inversely with the size of the animal and directly with the length of perfusion In experimental procedures no attempt was made to prevent this decline

Perfusion pressures (femoral artery pressure) varied between 80 and 100 mm Hg systolic and 30 and 50 mm Hg diastolic Insufficiencies in the circulating volume resulted in a fall in perfusion pressure Pressure tracings during the perfusion showed secondary waves following ventricular systole They were most marked in the diastolic phase of the pumping cycle and were abolished by ventricular fibrillation

The results of analysis of blood oxygen and flows are summarized in Table I Flows were measured by two methods The pump rate multiplied by the

TABLE I OXYGENATION OF BLOOD AND FLOWS AT END OF PERFUSION

	ARTERIAL		VENOUS				
	O_2 CONTENT (C C /100 ML)	O SATURATION (PER CENT)	O_2 CONTENT (C C /100 ML)	O SATURATION (PER CENT)	A V DIFF (C C /100 ML)	FLOW (ML /KG / MIN)	O CONSUMED (C C /KG / MIN)
Average	19 63	100 41	8 [illegible]6	41 95	11 38	33	3 4
S.D	±2 76	±4 75	±4 02	±14 35	±3 33		
Range							
minimum	12 52	93 05	2 65	17 34	4 23	15	1 2
maximum	23 83	108 74	15 34	62 90	16 71	55	6 2

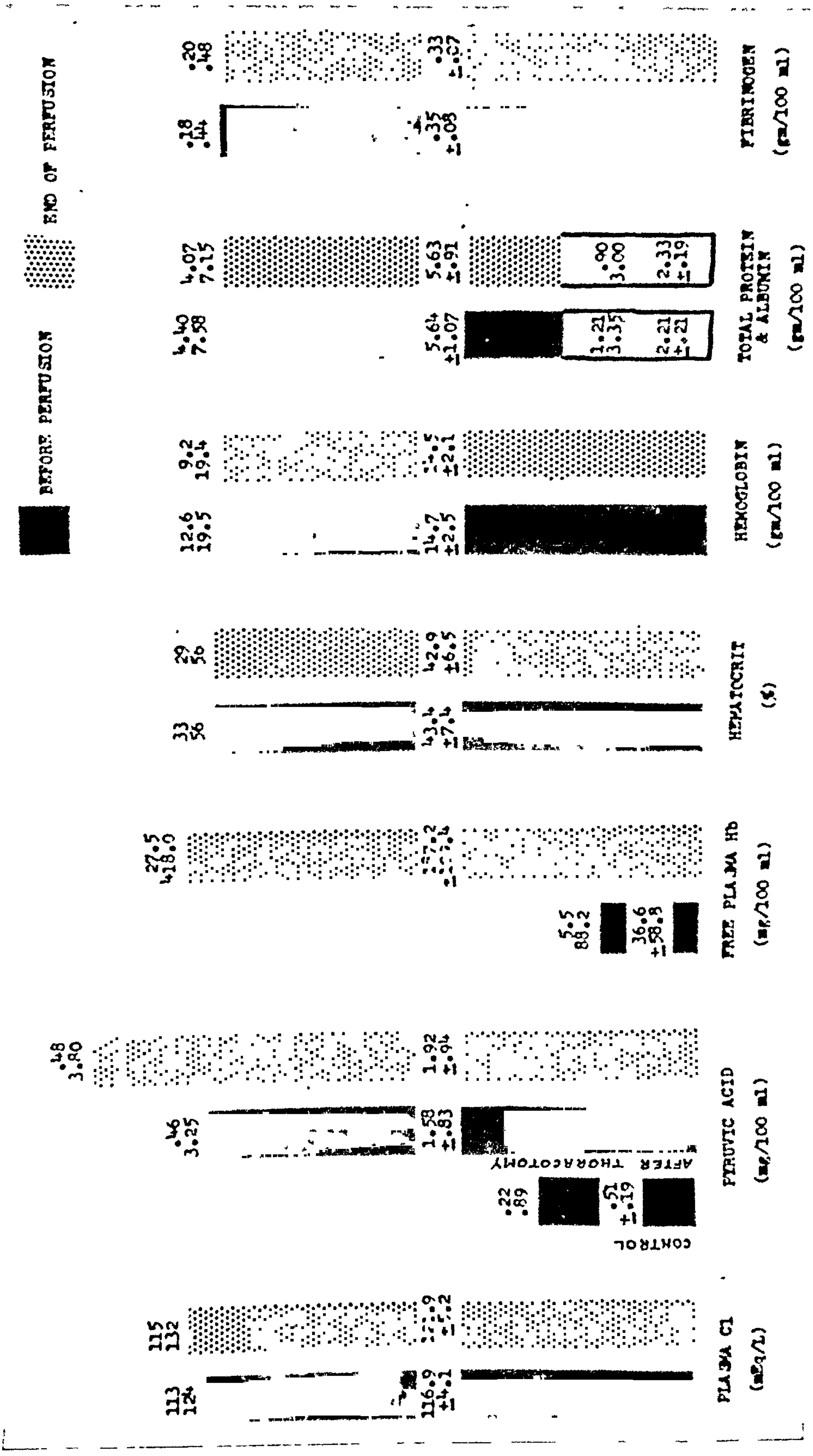

Fig. 3.—Results of blood determinations. (Figures at top of column represent the range of the average value which appears in the middle of the column with the standard deviation.)

stroke output corresponded with the flows recorded by the flowmeter For 31 dogs this averaged 33 ml per kilogram per minute (20 per cent of basal cardiac output[18]) and would place this pump oxygenator in the low flow category With this reduced turnover of blood, an average of 3.4 c c of oxygen per kilogram per minute was delivered to the tissues This was 40 per cent of the assumed basal oxygen consumption and was attributed to the increase in arteriovenous difference (coefficient of oxygen utilization[19]) The highest oxygen uptake in this series was 102 c c per minute in a 34-kilogram animal with a flow of 940 c c per minute This was well within the maximum oxygenating capacity of 130 c c per minute established for the rotating disc (four screens) oxygenator at a flow of 2 L under the standard conditions set forth by Gimbel and Engelburg[12], raising the oxygen saturation of hemoglobin from 60 per cent to 90 per cent

In the first ten perfusions, a single phase, positive pressure, mechanical respirator[20] was used The remaining experiments were conducted with an intermittent positive negative pressure respirator,* ventilating with 100 per cent oxygen and with a CO_2 absorption cannister in the circuit The efficiency of dual phase ventilation was displayed in the low pCO_2 and elevated pH in many of the blood samples obtained prior to perfusion [21] The resulting respiratory alkalosis appeared to have no adverse effects During perfusion there was a fall in the buffer bicarbonate and a further drop in the pCO_2 (Table II) The effectiveness of CO_2 exchange by the oxygenator is indicated by the arteriovenous CO_2 difference

TABLE II CHANGES OF CO AND pH BEFORE AND AT END OF PERFUSION

	BEFORE PERFUSION				END OF PERFUSION					
	ARTERIAL				ARTERIAL				VENOUS	
	CO_2 CONTENT (mM/L)	pCO_2* (MM HG)	HCO_3* (MEQ/L)	pH	CO CONTENT (mM/L)	pCO* (MM HG)	HCO_3* (MEQ/L)	pH	CO_2 CONTENT (mM/L)	A V CO_2 DIFF (mM/L)
Average	13.74	32	15.1	7.32	8.52	18	9.5	7.36	14.50	5.98
S D	±5.86			+.65	±2.87			±.69	±3.58	±2.24
Range										
minimum	5.41	13	5.6	7.00	2.77	<10	6.2	7.00	8.15	3.06
maximum	25.41	86	26.1	7.73	18.77	35	13.9	7.73	25.62	14.44

*Determined from nomogram of Singer and Hastings[34]

Comparison of the pyruvate levels in the donor reservoir and in the recipient animals prior to perfusion demonstrated an average increase of 209 per cent, the average rise during the by pass was 21 per cent This is shown graphically in Fig 3 Blood chloride appeared to rise slightly† and was due, in part, to the incomplete removal of isotonic sodium chloride used for flushing the by pass circuit free of formaldehyde The values for free plasma hemoglobin exceeded the levels mentioned in previous reports from this laboratory[7] The practice of replacing excessive operative losses with blood retrieved by suction (average free plasma hemoglobin—222 mg per 100 ml) was implicated Total protein and fractions were not altered significantly by perfusion. This has been confirmed by plasmaphoretic studies.[22] Hematocrit and hemoglobin were unchanged (see Fig. 3).

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* Air Shields Inc Hatboro Pa

†P value for difference between control and perfusion samples was .06

In the presence of a normal, reduced, or augmented circulating volume in the recipient, the venous pressure was positive when the drainage capacity of the caval catheters was less than the return to the heart and was negative if the capacity of the catheters exceeded the return. Successful perfusions were conducted under both conditions. As the most sensitive indicator of variations in the circulating volume, the venous pressure responded to changes of less than 50 ml. Fluctuations in the flowmeter curve, level of blood in the oxygenator, blood pressure and stroke rate of the pumps corresponded, to a lesser degree, with those in the venous pressure. These indices were used to maintain the circulatory volume during perfusion.

The average blood loss was 1,050 ml. (range, 125 ml. to 2,300 ml.). The average replacement was 1,300 ml. Perfusion and postoperative chest losses averaged 630 and 370 ml., respectively. A comparison of pre- and postoperative weights revealed a positive blood balance in the majority of perfusions.

The clotting time in 22 animals was restored to normal in an average period of two hours by a single dose of protamine. Additional increments were required in 9 animals. Thirty of the 31 dogs had normal clotting times by the fifth postperfusion hour. The average initial dose of protamine required for neutralization of circulating heparin was 4.6 mg. per kilogram. The absence of stoichiometric neutralization of the original heparinizing dose was attributed to the variation in potency of protamine lots and emphasized the need for titrations to arrive at the correct dosage.

Table III summarizes the data on fibrillation. The reversibility of coronary air embolism is shown in Table IV and was in accord with the work of Geoghegan and Lam.[23] The results indicated that neither body positioning nor the introduction of a ventricular vent provided complete protection from this hazard. Coronary air embolism was not observed in any of the 6 dogs in which fibrillation was deliberately induced. Incision through the septum into the left atrium in this group was accompanied by a continuous, occasionally vigorous, flow of arterialized blood from the left side. This was not observed in those hearts contracting regularly. Frequently, the blood level in the left atrium was displaced by air and remained below the incised septum. The diagnosis of coronary air embolism was established by direct inspection of coronary arteries and was confirmed by disturbances in rhythm, mottling and cyanosis

TABLE III. VENTRICULAR FIBRILLATION

CAUSE		PERIOD OF FIBRILLATION (MIN.)	DEFIBRILLATION	SURVIVOR	CAUSE OF DEATH
Placement of vent	1	28	1	1	
Coronary air embolism	4	14-41	3	2	Cerebral air embolism, cardiac standstill
Induced	6	14-34	6	6	

TABLE IV AIR EMBOLISM

DOG NUMBER	SOURCE OF AIR	PROPHYLAXIS	ECG	RESULTS	SURVIVAL
83	Septal defect	Vent	Ventricular fibrillation	Coronaries cleared of air, defibrillated	Survivor
100	Septal defect	Vent	No change	Coronaries cleared of air	Died 12 hours postperfusion of hemorrhage
300*	Septal defect	Vent	Current of injury	Reverted to normal ECG	Died at operation of cerebral air embolism
201	Septal defect	Vent	No change	Coronaries cleared of air	Died 18 hours postperfusion of cerebral air embolism
433	Septal defect	Position	Ventricular fibrillation	Coronaries cleared of air, defibrillated	Died 48 hours postperfusion of cerebral air embolism
475	Septal defect	Position	Ventricular fibrillation	Coronaries cleared of air defibrillated	Survivor
469	Catheter in left ventricle	Position	Ventricular fibrillation	Coronaries cleared of air, heart into standstill	Died at end of perfusion

*No air noted in coronary vessels

of the myocardium Clearance of air from the coronary vessels was accelerated by raising the perfusion pressure (increasing the air pressure activating the pumps), augmenting the circulating volume cardiac massage, and compression of the aorta distal to the subclavian cannula Three of the 6 animals whose hearts were returned to normal sinus rhythm succumbed to cerebral air embolism (see Table IV)

There were 22 survivors in thirty one perfusions Four of nine deaths were attributed to air embolism One of the animals (433) survived for 48 hours and demonstrated opisthotonos extensor rigidity, hyperreflexia, and hyperirritability Vascular changes associated with cerebral air embolism were observed at autopsy[24, 25] A dissecting aneurysm in one animal was ascribed to a tear in the intima of the left subclavian artery at the aortic junction, caused by a metal cannula Two dogs died of intrapleural hemorrhage 12 hours postoperatively Extensive damage to the interatrial septum and loss of an airway were responsible for two deaths

There was a late mortality (more than 5 days postoperative) consisting of 10 dogs These deaths, for the most part, were caused by wound infection with empyema Two of these were secondary to sternal separations of transsternal incisions One animal which was perfused through the femoral artery and vein developed congestive heart failure and pulmonary edema Autopsy disclosed that a margin of the septal incision had been sutured to the "valve" of the inferior vena cava, shunting the blood from it into the left atrium Severe stenosis of the inferior vena cava due to the atrial wall suture was the cause of death in another animal The use of the right atrium for placement of caval catheters which serve as guides during suture, has prevented repetition of these errors An infected thrombus adherent to the septal suture line was found in another animal with empyema

Gross examination of the hearts of all but 2 of the 12 animals sacrificed at intervals up to eight months disclosed healed, smoothly endothelized intra cardiac incisions. A thickened mural plaque and a calcified pedunculated thrombus, both overlying the septal suture line, were seen in 2 animals. Inspection of the abdominal viscera revealed no evidence of recent or healed infarcts.

On the basis of these experimental investigations, the apparatus was employed in a clinical case.

CASE REPORT

J. B., an 18-year-old girl, a known ''cardiac'' since the age of one year, complained of limited exercise tolerance, exertional dyspnea, and precordial pain. On admission to the hospital, physical examination revealed a well-developed white female (53 Kg.) who presented a left precordial bulge. There was a harsh systolic murmur (Grade 3) heard loudest over the pulmonic area; the second pulmonic sound was diminished. No cyanosis or clubbing was noted. Chest x-ray showed enlargement of the right ventricle with a prominent left heart border. The electrocardiogram revealed a right ventricular strain pattern. Angiography demonstrated simultaneous opacification of the pulmonary artery and aorta. Catheterization data* are summarized in Table V. They were interpreted as indicating the presence of an interatrial septal defect with pulmonic stenosis of the infundibular type. The predominant shunt was left to right. On exercise, a slight right-to-left shunt was noted. On June 30, 1955, open heart surgery was performed through a transsternal incision. The patient underwent total body perfusion and an atrial cardiotomy was made in the excluded heart. A large foramen ovale type defect, 3 cm. by 5 cm., was obliterated with interrupted sutures. During the repair, a pool of blood was maintained over the defect to prevent air from entering the left side of the heart. Following closure of the right atrium, a 2 cm. incision was made in the right ventricular outflow tract and the right ventricle digitally explored. No infundibular stenosis was detected and the cardiotomy was closed. The patient's heart was excluded for 23 minutes during which time the extracorporeal flow rate averaged 36 ml. per kilogram per minute. The patient was awake at the conclusion of the procedure. Her postoperative course was uneventful and she was discharged on the thirtieth hospital day.

TABLE V. CATHETERIZATION DATA—PATIENT J. B.

LOCATION OF SAMPLE	PREOPERATIVE		POSTOPERATIVE	
	PRESSURE (MM. HG)	O_2 CONTENT (C.C./100 ML.)	PRESSURE (MM. HG)	O_2 CONTENT (C.C./100 ML.)
Pulmonary capillary	11	16.0	10	15.7
Pulmonary artery	20/12	15.4	23/13	11.9
Right ventricle (infundib.)	27/10	15.8	-	-
Right ventricle (sinus)	60/0	-	37/0	11.5
Right atrium	10	14.7	10	11.6
Superior cava	-	11.9	-	9.5
Brachial artery	-	16.0*	-	15.9†
Brachial artery (after exercise)	-	15.6‡		
Pulmonary blood flow	7.5 L./min.		5.8 L./min.	
Systemic blood flow	1.1 L./min.		5.1 L./min.	
Shunt, left-to-right	6.4 L./min.		0.7 L./min.	

*94.3 per cent saturated.
†94.5 per cent saturated.
‡92.0 per cent saturated.

Six months later she was recatheterized. The data (see Table V) indicated a small left-to-right shunt (0.7 L. per minute) which was considered to be of no clinical significance. At this time she was free of exertional dyspnea and was engaging in unrestricted activity.

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*Courtesy of Drs. Harold A. Lyons and John J. Kelly.

DISCUSSION

The results of these experiments show that the important metabolic changes occurring in a total by-pass are confined to the factors regulating acid-base balance. The appearance of a metabolic acidosis in perfused dogs has been attributed to a rise in fixed acid.[6, 26, 27] Pyruvic acid levels above 4 mg. per 100 ml. have been associated with a poor prognosis.[9] In this series, the increase in pyruvate was of minimal significance. The fall in bicarbonate buffer (see Table III) indicated that other acid metabolites were accumulating during perfusion. An appreciable increase in lactic acid has been reported.[26] Hyperventilation with a dual phase respirator in the preperfusion period and excessive elimination of CO_2 by the screen oxygenator during the by-pass produced a marked depression of the arterial pCO_2. This served to compensate for the metabolic acidosis, maintain the pH within normal limits and improve the oxygen uptake of hemoglobin (Bohr effect). Similar observations have been made with cross circulation techniques where an increase in the donor respiratory minute volume was used to control the fall in recipient pH.[27] Measures to regulate the pH by the addition of Na HCO_3 or flushing the oxygenator with 5 per cent CO_2 and 95 per cent oxygen were not employed.

Hemoglobinemia in hypotensive states has been recognized as a cause of renal damage in man.[28] However, under low perfusion pressures such as obtained in these experiments, no ill effects were noted even when the free plasma hemoglobin levels were in excess of 400 mg. per 100 ml The recent adoption of a low-vacuum, variable suction pump has avoided foam formation and reduced the red cell destruction in the aspirated blood returned to the circuit.

In our experience the prime requisite for control of postperfusion hemorrhage and the restoration of normal clotting was complete reversal of heparinemia with protamine. Fractional protamine titrations obtained at regular intervals in the recovery period indicated reduced but significant concentrations of circulating heparin (5 to 10 mcg. per milliliter) which prevented normal clotting.[14] The existence of a heparin rebound phenomenon has been postulated to explain the persistence of circulating heparin despite adequate neutralizing doses of protamine.[4] The role of the fresh whole blood transfusion requires further evaluation. In early experiments it was given routinely at the completion of the by-pass to replace destroyed clotting factors, equalize postoperative losses and avoid the introduction of other anticoagulants. More recent evidence indicates that with a normal or slightly positive blood balance at the end of perfusion, adequate protamine dosage alone will restore the clotting time. Protracted perfusions (over one hour) appear to enhance postoperative bleeding. The hemorrhagic deaths in 2 dogs early in this series were ascribed to abnormal hemolytic and proteolytic activity due to plasma fibrinolysin[29] or bacterial contamination.[30] The impression has since been gained that these deaths can be averted by stricter attention to the details of postoperative care.

Exposure of the left side of the isolated contracting heart to the atmosphere directly or through septal defects predisposes to systemic air embolism. In 6 animals, incisions into the interatrial septum were accompanied by the entry of air into the left atrium an competent mitral valve, bronchial artery return admixed with air was ejected into the systemic circulation in systole. Continued circulation through the left side of the heart made it difficult to preserve a level of blood or saline solution in the right atrium over the incised septum. Extracorporeal circuits which employ low perfusion pressures and deliver pulsatile flows are unable to maintain continuous closure of the aortic valves. Ventricular systolic pressure exceeds the perfusion pressure, especially in the diastolic phase of the mechanical pump, and ejection of air and blood into the aorta follows. Cookson and Costas-Durieux,[31] using hypothermia supplemented by arterial transfusions in open cardiotomies, stated that a nonpulsatile flow at a pressure of 70 mm. of Hg prevented opening of the aortic valves in ventricular systole; the technique was not uniformly effective in avoiding air embolism in their animals. Potassium-induced cardiac arrest has been advocated by Melrose and his group.[32] This method requires occlusion of the aorta above the coronary ostia, thereby limiting the period of by-pass and depriving the myocardium of the benefits of continuous perfusion. Miller and associates[15] have employed a left ventricular vent in experimental procedures and in a successful clinical case with an interatrial septal defect. In our hands, this method failed to eliminate coronary and/or cerebral air embolism in 4 of the 13 dogs in which it was used. Previous experience with 5 cases of ventricular fibrillation (4 due to coronary air embolism and one due to placement of a ventricular vent) had demonstrated the excellent protection afforded the heart by uninterrupted perfusion of the coronaries with oxygenated blood (see Table III). Accordingly, fibrillation to abolish ventricular ejection, as first proposed by Glenn and Sewell[33] and Senning,[10] was deliberately induced in 6 dogs with gratifying results. The "sucking action"[33] of the ventricle in diastole was replaced by a persistent flow of blood from the left atrium through the septal defect. Air embolism was not observed. Operative techniques were expedited by the quiet field. Myocardial tone and color remained satisfactory throughout the by-pass. There was a coarse fibrillatory pattern on the electrocardiogram. The hearts were defibrillated with ease soon after closure of the cardiac incisions. Promptness in restoring regular contractions reduced the tendency of the chambers to dilate because of the accumulation of coronary venous and bronchial artery blood. All 6 animals survived and at autopsy showed no myocardial damage attributable to fibrillation. The use of ventricular fibrillation as an adjunct to perfusion in the direct approach to lesions of the left side of the heart is currently being explored.

The available evidence indicates that the venous pressure is a valuable guide to the progress of a perfusion. This study will be presented in a separate paper.

SUMMARY

1. A simplified pump-oxygenator with safeguards against the introduction of air is described.

2. Interatrial septal defects were created and repaired under direct vision in 31 dogs with 22 survivors. During this study, techniques have been developed which appear to have reduced the hazards of total body perfusion.

3 Protamine titrations are an important factor in the control of postperfusion bleeding

4 The principal metabolic change during perfusion is the development of a metabolic acidosis The desirability of a low arterial pCO_2 to counteract this is discussed

5 The case report of a successful closure under direct vision of an interatrial septal defect in an 18 year old girl is presented

6 Deliberately induced ventricular fibrillation can eliminate air embolism during open cardiac surgery *

The authors wish to acknowledge the catheterization studies performed by Dr Harold A Lyons and Dr John J Kelly of the Department of Medicine, and the technical assistance of Miss LaVonne A Young, Mrs Alva C Riddick, Mr Herbert Lauritzen, and Mr Ludwig Quabeck

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*Since the preparation of this report induced fibrillation has been employed effectively in the direct vision repair of 2 clinical cases of interventricular septal defect

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ELIMINATION AND TRANSPORT OF MUCUS IN THE LUNG

AN EXPERIMENTAL STUDY

EDWARD G. HUPPLER, M.D.* (BY INVITATION), O. THERON CLAGETT, M.D.,**
AND JOHN H. GRINDLAY, M.D.*** (BY INVITATION)
ROCHESTER, MINN.

WHEN a lobar bronchus is completely obstructed or transected in the absence of infection, the lung becomes atelectatic and the major bronchi become filled with mucus. However, the lung does not become a mucocele nor do the bronchi become cystic because of accumulated secretions of the respiratory tract. This is illustrated clinically by cases of traumatic rupture of the bronchus. If the patient survives the early posttraumatic period, the unrepaired ruptured bronchus closes completely and the major bronchi contain viscid, noninfected mucus. Many authors[1-5] have reported cases in which plastic repair of bronchi following traumatic rupture has resulted in ultimate physiologic recovery of the involved lung. This has been confirmed experimentally by Webb and Burford.[6] If infection is superimposed upon obstruction, a cystic form of bronchiectasis results.[7-10]

What happens to mucus and secretions in a lung that has the bronchus transected? It seems that there are two possibilities. If the secretions cannot be removed through the tracheobronchial tree, either they must be eliminated in the lung or the production of secretions must cease.

Some authors[11-19] believe that retained secretions are important in the pathogenesis of pulmonary cysts of the bronchogenic type. Alveolar agenesis has been observed in the pulmonary parenchyma surrounding bronchogenic cysts.[13, 16, 20-24] The question arises whether the lobules of the lung might be the site of elimination of secretions and whether the stage of development of the alveoli is a determining factor in the production of bronchogenic cysts.

In 1910, Pitt[25] suggested that mucus might be removed through the distal part of the pulmonary tree when bronchi are obstructed. Ross[26] has observed that the macrophages and their ingested substances wander back into the alveoli from which they came, when the bronchial tree is obstructed.

On the basis of these observations the following two hypotheses have been formulated: (1) After transection of a bronchus, in the absence of infection, mucus that is *normally* secreted into the bronchi is phagocytosed in the alveoli.

Abridgment of thesis submitted by Dr. Huppler to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Science in Surgery.

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Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

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(2) *If a segment of viable bronchus has both ends closed, a bronchogenic cyst will result from the accumulation of endobronchial mucus.* These hypotheses were tested experimentally in 29 dogs.

METHOD

In a control group of dogs the right upper-lobe bronchus was transected and both ends of the divided bronchus were closed by suture (Fig. 1). In these animals, mucus secreted into the right upper-lobe bronchus could not be removed through the trachea by coughing or by movement of the cilia but it could flow into the alveoli.

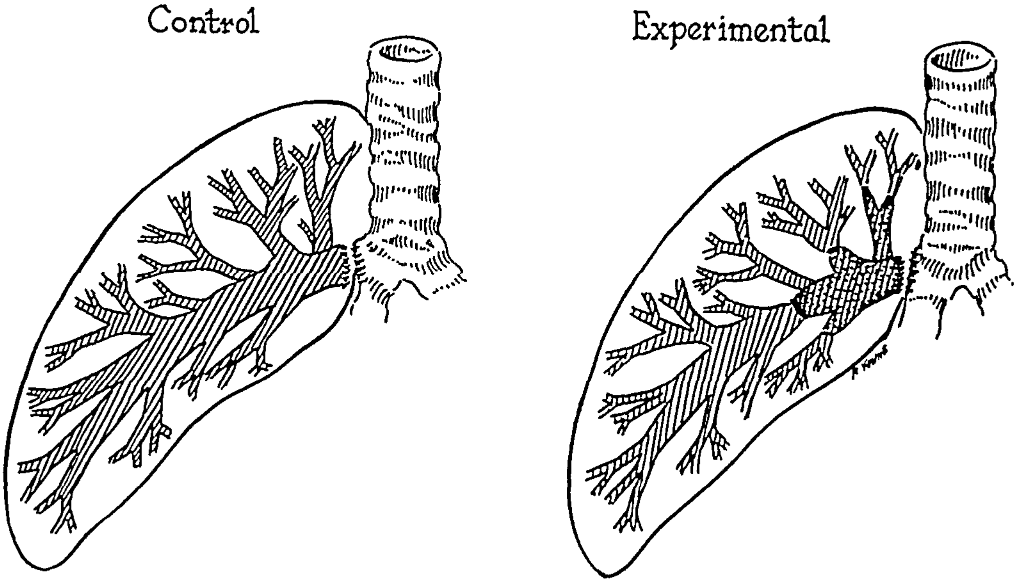

Fig. 1.—Diagram to illustrate the surgical procedures performed. In the control animals, the lobar bronchus was transected and the bronchial stumps were sutured proximally and distally. In the experimental animals, the secondary bronchi were doubly ligated and then the bronchial stumps were sutured. This produced an isolated bronchial segment represented by the cross hatching and stippling.

In the experimental group of animals the right upper-lobe bronchus was transected and the divided ends were closed as in the control animals. In addition, the first four secondary bronchi and the main continuation of the primary bronchus were doubly ligated, thus producing an isolated segment of bronchus. Mucus secreted into this segment could not be removed through the trachea nor could it flow into the alveoli. In the experimental animals the secondary bronchi distal to the isolated segment of bronchus were not ligated; hence, mucus secreted into the bronchus distal to the isolated segment could flow into the alveoli but not into the trachea (see Fig. 1). All of the dogs were given antibiotics for 5 days postoperatively. An animal from each series was killed at varying intervals from 2 to 48 weeks after operation.

RESULTS

The pathologic changes were confined to the right upper lobe. This lobe was small, purplish red, and atelectatic, and the lobes from both groups of animals appeared identical. With one exception, a bronchial cyst was not produced in the isolated segment of bronchus. The bronchi were dilated an average of two and one-half times the normal diameter and were filled with clear, glary, tenacious mucus (Fig. 2). Measurements of displacement volumes and bronchial diameters did not distinguish specimens of the control group from specimens of the experimental group. From the gross observations it appears that factors other than retention of secretions in an isolated segment of bronchus may be responsible for the formation of bronchogenic cysts.

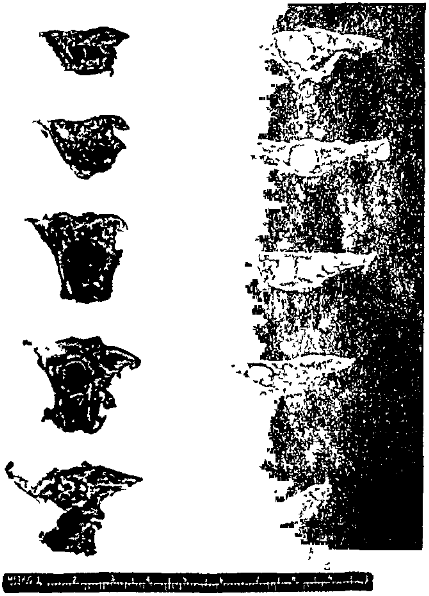

Fig 2.—Bronchi dilated and full of clear, glary, tenacious mucus The right upper lobe of the experimental series is indistinguishable grossly from that of the control series.

Blocks of tissue were taken from each specimen through the region of the isolated segment, through the region just distal to the isolated segment and through the tip of the lobe, in both the control and the experimental animals (see Fig. 1). Sections were specially stained to demonstrate mucus. The most significant histologic changes observed were in the alveoli of the region surrounding the isolated segment of bronchus of the experimental animals. Essentially no mucus was present in the respiratory ducts and alveoli and consequently there was no phagocytosis of mucus in the alveoli surrounding the isolated segment of bronchus (Fig. 3). This was as expected because most of the mucus was trapped in the isolated segment of bronchus.

However, mucus was seen in the alveoli of the control animals and also in the alveoli that were distal to the isolated segment of bronchus of the experimental animals (Fig. 4). In the lobules of the lungs of the control animals phagocytes could be seen ingesting mucus within the alveoli (Fig. 5). The terminal bronchi and alveoli did not become cystic, because the secretions were phagocytosed and removed in the lobule of the lung.

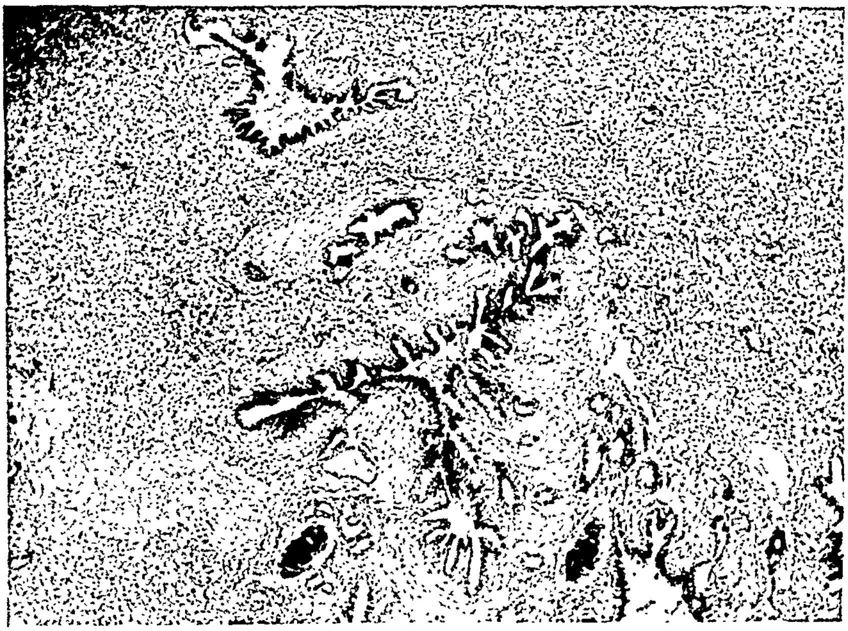

Fig. 3.—Section through pulmonary parenchyma surrounding the isolated segment of bronchus of an experimental animal. There is essentially no mucus in the respiratory ducts and alveoli and consequently no phagocytosis of mucus (mucicarmine; ×50).

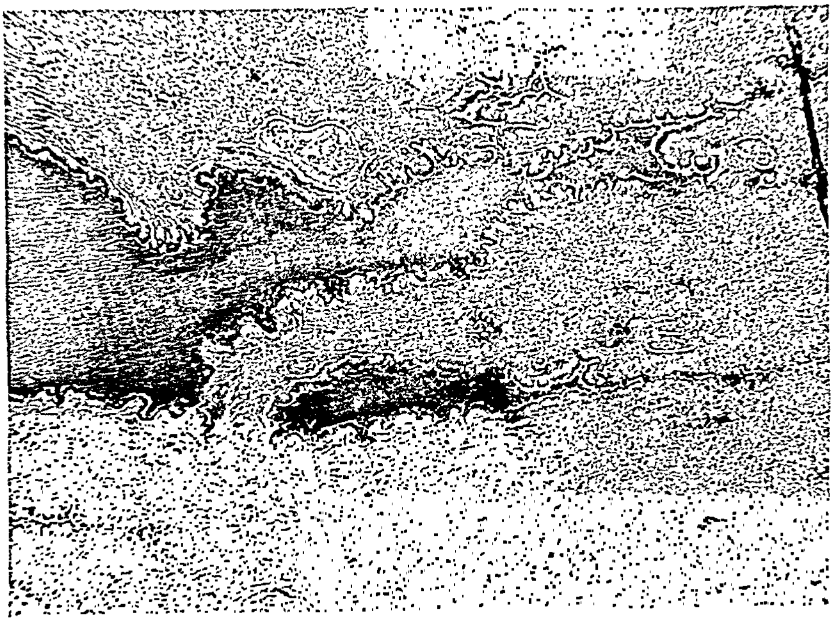

Fig. 4.—Section through pulmonary parenchyma of control animal. Note mucus in bronchioles, respiratory ducts, and a few alveoli (mucicarmine; ×30).

The epithelial lining of the bronchi remained intact, but the ciliated columnar cells underwent metamorphosis and were largely replaced by non-ciliated goblet cells which contained mucus. The mucus within the goblet cells was blended with, and indistinguishable from, the large mass of clear mucus in the bronchial lumen The bronchial cartilages were widely separated and spaced about the dilated bronchus and there was fragmentation of the elastic fibers of the perichondrium. The tubulo-acinar glands were dilated and mucus was seen within the acini.

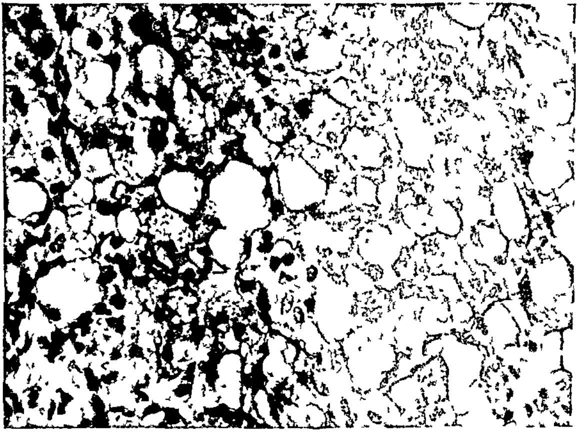

Fig 5—Phagocytes ingesting mucus within the alveoli (mucicarmine, ×400).

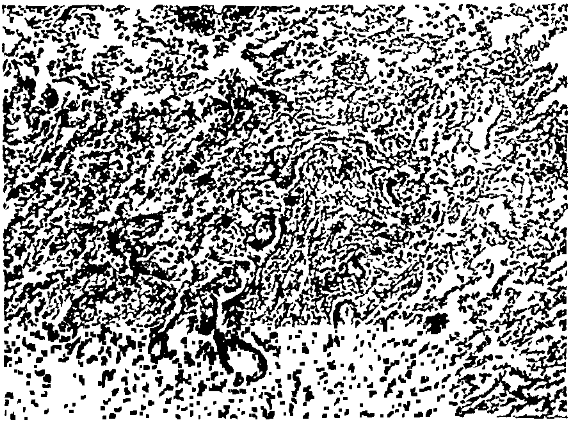

Fig 6—Experimental animal killed 44 weeks after operation Mature fibrous tissue obliterates a bronchiole (hematoxylin and eosin; ×100)

Two weeks after operation, granulation tissue partly occluded the lumina of about 10 per cent of the bronchioles (Fig. 6). Twelve weeks after operation the granulation tissue had been converted into poorly vascularized fibrous tissue which contained moderate amounts of collagen, but this mature granulation tissue did not involve more and more bronchioles.

In animals killed 16 to 48 weeks after operation, the large bronchi remained full of mucus and the epithelium was flattened out. During the same interval there was a decrease in the degree of dilatation of the smaller bronchioles and the respiratory ducts. Fig. 7 shows that the normal convolutions had returned to the bronchiolar epithelium and that the bronchioles were no longer distended with mucus.

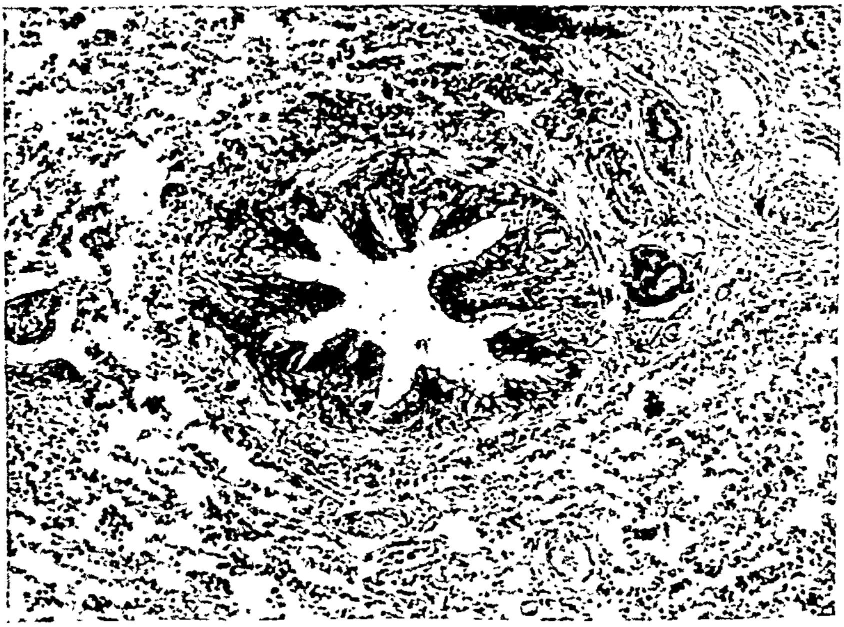

Fig. 7.—Experimental animal killed 42 weeks after operation. The convolutions have returned to the bronchial epithelium and the bronchioles are no longer distended with mucus. Phagocytes in the lobules of the lung have already removed the mucus (mucicarmine; ×100).

COMMENT

These experiments have reaffirmed the many clinical and experimental observations that complete bronchial obstruction *without* infection results in bronchial dilatation by clear mucus.

Essentially the same pathologic condition was produced experimentally by transection of a lobar bronchus as occurs in patients with traumatic rupture of a bronchus. As with traumatic rupture of a bronchus, a mucocele of the lung did not develop, apparently because the secretions that flowed into the lobules of the lung were phagocytosed and carried away.

It has been suggested[18, 19] that cystic bronchiectasis results when mucus dilates the terminal part of the bronchial tree. In these experiments the mucus dilated the terminal part of the bronchial tree, but not cystically. It was at this locus that phagocytes removed mucus, and here the bronchial tree returned to a normal contour—it did not undergo cystic dilatation The isolated segment of bronchus is comparable to a bronchogenic cyst that has no connection with the tracheobronchial tree and that also is associated with agenesis of the surrounding alveoli The isolation of a segment of bronchus approximates the congenital defect postulated by some authors[11, 19] to be the cause of bronchogenic cysts However, with this technique, unequivocal bronchogenic cysts were not produced One is tempted to speculate that bronchogenic cyst is not the result, but rather the cause, of apparent alveolar agenesis with resulting inability to eliminate secretions by phagocytosis However, the data and the interpretation of the data obtained from an experimental study such as this are not necessarily explanatory of the disease process in man

SUMMARY AND CONCLUSIONS

Phagocytosis and removal of mucus were seen histologically in the lobules of the lung when mucus could flow into the respiratory ducts, alveolar ducts, and alveoli In an experimental group of animals in which the main quantity of secretion was isolated in a bronchial segment, little mucus was present in the lobules of the lung and hence little was available for phagocytosis In a control group of animals in which the secretions of the respiratory tract could flow into the lobules of the lung, the mucus was phagocytosed and carried away

It is concluded that, when the tracheobronchial tree is completely occluded in the absence of infection, secretions of the respiratory tract are removed in the lobule of the lung by the process of phagocytosis When the secretions are retained in an isolated segment of bronchus, a bronchogenic cyst is not produced The most likely explanation for this—and the one most in accord with present knowledge of the physiology of secreting cells—is that mucous glands and goblet cells secrete until the endobronchial pressure becomes so great that the glands can no longer continue to secrete against the pressure within the bronchial lumen

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SURGICAL TREATMENT OF VENTRICULAR SEPTAL DEFECTS: A METHOD UTILIZING SELECTIVE CORONARY PERFUSION AND HYPOTHERMIA

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THE use of hypothermia in the manner suggested by Bigelow and his associates[1] to perform intracardiac surgery under direct vision has proved to be a remarkably valuable and safe method for the closure of interatrial septal defects and for incision of the valve in pulmonary valvular stenosis. Attempts to use this method to produce and repair interventricular septal defects in experimental animals soon disclosed that right ventriculotomy under hypothermia is a hazardous procedure. Ventriculotomy alone under hypothermia with inflow-outflow occlusion of the heart has been shown by many investigators to be complicated by ventricular fibrillation with failure of the experimental animals to survive in an exceedingly high percentage of the experiments. Adding to this the dangers inherent in operating upon the ventricular septum under direct vision, the more important of which are injuries to the conduction system and coronary air embolism, the risk of applying this method to the repair of interventricular septal defects in human beings was made prohibitive. This led to an intensive study of the metabolic changes in the heart muscle responsible for the production of ventricular fibrillation and to the demonstration by Shumway, Gliedman, and Lewis,[2] and others, that perfusion of the coronary arteries with arterialized blood was effective in sharply reducing the incidence of ventricular fibrillation, and that resuscitation was readily accomplished in those instances where it did occur. The demonstration by Shumacher and his associates,[3] of the role played by the autonomic nervous system in the production of ventricular fibrillation together with the effectiveness of sino-auricular node blockade in preventing its occurrence, further decreased the hazards of this complication. Successful results following operations on the right ventricle and interventricular septum in hypothermic dogs, using cardiac occlusion, coronary perfusion, and sino-auricular node blockade, encouraged us to apply this method clinically in selected patients. This paper presents our experience with the use of this method in 10 patients with interventricular septal defects (Table I).

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TABLE I

CASE AGE (YR.)	PRESSURE MM. HG		RESULT	COMMENT
	P.A.	R.V.		
1. S.Y. 1½	70/28	60/14	Survived	No murmur
2. W.S. 30	76/15	74/0	Survived	Much improved; no murmur; working; P.O. catheterization, P.A. 44/14, no shunt
3. M.L. 34	?	76/0	Died	Ventricular fibrillation 5 minutes following release of occlusion tapes; defibrillation unsuccessful; extreme pulmonary arteriosclerosis
4. S.H. 4½	60/26	66/0	Survived	Murmur present; doing well
5. M.H. 6½	118/52	112/0	Survived	Murmur present; P.O. catheterization, P.A. 45/15; no shunt
6. F.A. 11	63/20	62/2	Survived	Murmur present; weight gain; no dyspnea
7. L.M. 9	70/24	70/0	Died	Cardiac decompensation due to aortic insufficiency result of distortion by suture; died two months following operation; defect closed
8. L.M. 8	100/50	100/0	Survived	Murmur present; P_2 decreased; heaving cardiac impulse no longer present
9. C.O. 6	110/78	124/8	Survived	Murmur present; stormy postoperative course; cardiac failure difficult to control; gradual improvement now
10. S.M. 10	112/48	106/0	Died	Complete heart block with ineffective rate following release of occluding tapes; defect closed

METHOD

Intratracheal gas-oxygen-ether anesthesia supplemented by hypothermia was used in each case. The body temperature at the time of the occlusion varied from 80° to 83° F.

The technique of coronary artery perfusion was similar to that described by Shumway and his co-workers,[2] and differed only in the method of pumping the blood into the isolated aortic arch. The blood used for perfusion was arterialized venous blood collected into heparin-glucose solution, and was drawn from donors shortly before using and kept at a temperature of 90° F. until the time of perfusion. Umbilical tapes were placed around the following vessels: (Fig. 1) both venae cavae, the innominate artery, the left common carotid artery, the pulmonary artery, and the aortic arch between the left common carotid and the left subclavian arteries. A plastic catheter was placed in the right subclavian artery at the apex of the pleural space and advanced into the ascending aorta. In some cases the catheter was inserted into the left subclavian artery, and in these cases the tape on the aortic arch was placed distal to the left subclavian artery The distal end of this catheter was connected to a system of three three-way stopcocks by plastic tubing The bottles of oxygenated blood were connected to this system of stopcocks by plastic tubing Two siliconized 20 c c glass syringes were also connected to the stopcocks

After infiltrating the sino auricular node region with one per cent Novocaine, the tapes on the venae cavae and the aortic arch were tightened and, after allowing time for the heart to empty, the tapes on the pulmonary artery, innominate artery, and left common carotid artery were tightened The incision in the right ventricle was made and the coronary artery perfusion begun, the oxygenated blood being alternately pulled from the reservoir into the syringe and injected into the isolated proximal aorta The rate of perfusion has been approximately 2 c c per pound per minute, and even in adult patients has not exceeded 120 c c per minute (Table II) The septal defects have been closed using a running or interrupted silk sutures Ringer's solution was injected into the left ventricular cavity before complete closure of the defect, and into the right ventricle before completely closing the incision in the right ventricle The occluding tapes on the venae cavae, pulmonary artery, innominate artery and left common carotid artery were then released The tape on the aortic arch was not removed until the heart had resumed a strong, effective beat

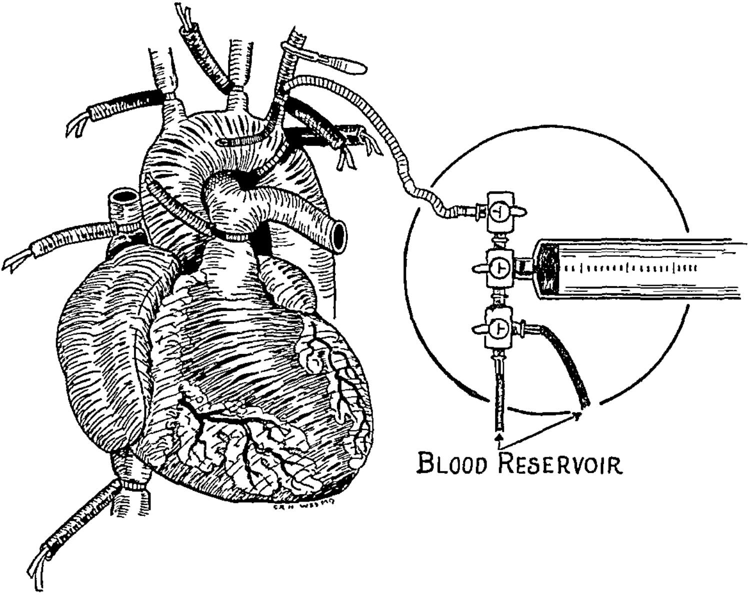

Fig 1

TABLE II

	CASE AGE (YR.)	OCCLUSION TIME (MIN.)	CORONARY ARTERY PERFUSION (C.C.)	VENTRICULAR FIBRILLATION
1.	S.Y. 1½	14½	493	0
2.	W.S. 30	10	1100	0
3.	M.L.	10	820	Five minutes after release of occlusion tapes; could not be defibrillated
4.	S.H. 3½	9	420	0
5.	M.H. 6½	12	750	0
6.	F.A. 11	8	600	Inadvertent use cold blood for perfusion (76°F.); defibrillated
7.	L.M. 9	10½	740	0
8.	L.M. 8	9½	650	0
9.	C.O. 6	10	500	0
10.	S.M. 12	11	750	0

RESULTS

This method has been employed in 10 patients with interventricular septal defects; 7 of these 10 have survived (see Table I). All 10 patients had symptoms varying from moderate exertional dyspnea and fatigue to repeated episodes of cardiac failure. In all 10 cases, there were loud harsh systolic murmurs along the left sternal border and moderate to marked cardiac enlargement. The second pulmonic sound was accentuated. Electrocardiograms revealed right ventricular hypertrophy and demonstrated diastolic overload patterns in most cases. Cardiac catheterization revealed moderate to marked right ventricular and pulmonary artery hypertension and a left-to-right shunt at the ventricular level. None of the surviving patients has shown evidence of neurological injury. In 2 patients, murmurs are no longer present. All those surviving have shown improvement as evidenced by less dyspnea, a more quiet heart action, decreased intensity of the second pulmonic sound, and less vascular lung fields. Cardiac catheterization four months after operation in cases Nos. 2 and 5 showed no evidence of a shunt and there was a notable decrease in the pulmonary artery pressure.

In 2 cases, excessive postoperative bleeding required a second thoracotomy (Table III). The amount of drainage in the chest bottles following operation in these patients has exceeded the amount one would expect in operations not employing hypothermia, cardiac occlusion, and perfusion. Studies of bleeding and clotting times, prothrombin and prothrombin consumption times, and

TABLE III

CASE	POSTOPERATIVE BLEEDING	DISTURBED CONDUCTION POSTOPERATIVE
1	0	0
2	0	Partial RBBB pre- and postoperative
3	–	–
4	Chest reopened, internal mammary vessel	Complete RBBB
5	Chest reopened, diffuse oozing	Complete RBBB
6	0	0
7	0	0
8	0	RBBB pre- and postoperative
9	0	Complete RBBB
10	–	Complete heart block (died in operating room)

of fibrinolysin activity of the blood in these cases have been done with no constant abnormality having been noted. Vitamin K_1 oxide has been used empirically in the more recent cases and there seemed to be less drainage in these patients. Complete heart block occurred in one patient following re-establishment of the circulation, and death occurred in the operating room because of the very slow heart rate. Complete right bundle branch block occurred in 3 of the 7 surviving patients.

DISCUSSION

In all of the cases, the heart action during the period of coronary artery perfusion was excellent. There was active bleeding from the small branches of the coronary arteries divided in the line of the ventriculotomy incision, and the myocardium remained a uniformly pink color. Ventricular fibrillation occurred in 2 cases following re-establishment of the circulation (see Table II). In case No. 6, it was possibly related to the perfusion of cold blood. Defibrillation in this patient was readily accomplished. Ventricular fibrillation also occurred in case No. 3 and was irreversible. Post-mortem study in this patient showed the most marked degree of pulmonary arteriolosclerosis that we have seen, and the myocardium contained focal areas of subacute necrosis.

From our limited experience, we feel that the method described effectively prevents coronary air embolism by keeping the aortic valves closed during the period that the ventricles are open, since there were no instances of this complication in the series. Although we seem to be able to eliminate or materially reduce the hazards of ventricular fibrillation and coronary air embolism, the time limits of the procedure do not allow for accurate evaluation of injuries to the conduction system during the placement of sutures and would not allow sufficient time for the placement of a prosthesis should it not be possible to close the defect by suture methods. In addition, the technical difficulties and very real risk inherent in hypothermia itself must be taken into account. This method was undertaken before effective pump-oxygenators were available. However, we feel that all methods using hypothermia in direct vision cardiac surgery will inevitably be supplanted by the development of a safe, relatively simple, effective pump-oxygenator.

SUMMARY

1. Seven out of 10 patients survived closure of interventricular septal defects employing a method utilizing hypothermia, sino-auricular node blockade, cardiac occlusion, and selective coronary artery perfusion.

2. The method has the disadvantages and hazards of hypothermia itself and, in addition, the time limit imposed by interruption of the cerebral blood supply does not permit unhurried repair of the defect by whatever method seems most suitable in the individual case.

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A REPORT ON HETEROLOGOUS VASCULAR SHUNTS (BOVINE BRACHIOCEPHALIC) IN EXPERIMENTAL AORTIC ARCH RESECTION

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SURGICAL resection of the aortic arch poses two major unsolved problems (a) a practical method for by passing the aortic arch during the period of occlusion, and (b) a suitable graft for its reconstruction This report primarily concerns progress in the experimental solution of the first of these problems

Our experience in the use of a three limbed plastic shunt constructed of 10 mm bore Tygon tubing and siliconed glass joints in experimental resection of the dog's aortic arch[1] and its technically successful (but fatal) application in a clinical case[2] have been previously described An external shunt of similar principle but fashioned of Ivalon sponge[3] and a combination of Ivalon sponge and horse carotid arteries[4] has been used by DeBakey and Cooley in two technically successful resections of the human aortic arch In the former of the 2 cases, thrombosis was experienced in the innominate artery limb of the shunt

Although the Tygon shunt was successfully used in experimental resection of the dog's arch by us, the semirigid system proved cumbersome and dominated the operative field Accordingly, a shunt of more desirable physical properties was sought and a suitable multilimbed heterologous vascular shunt was obtained by taking advantage of the fact that the bovine aortic arch has but one branch a common brachiocephalic trunk This vessel and its carotid and subclavian artery branches are fashioned into a multilimbed shunt by oversewing the stump of the brachiocephalic Experience in the use of this shunt in aortic arch resection attempted in 24 dogs forms the basis of this report The method of procurement of the shunt vessels and technical improvements in experimental aortic arch resection including the adjunct use of hypotension are also described

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United States Navy

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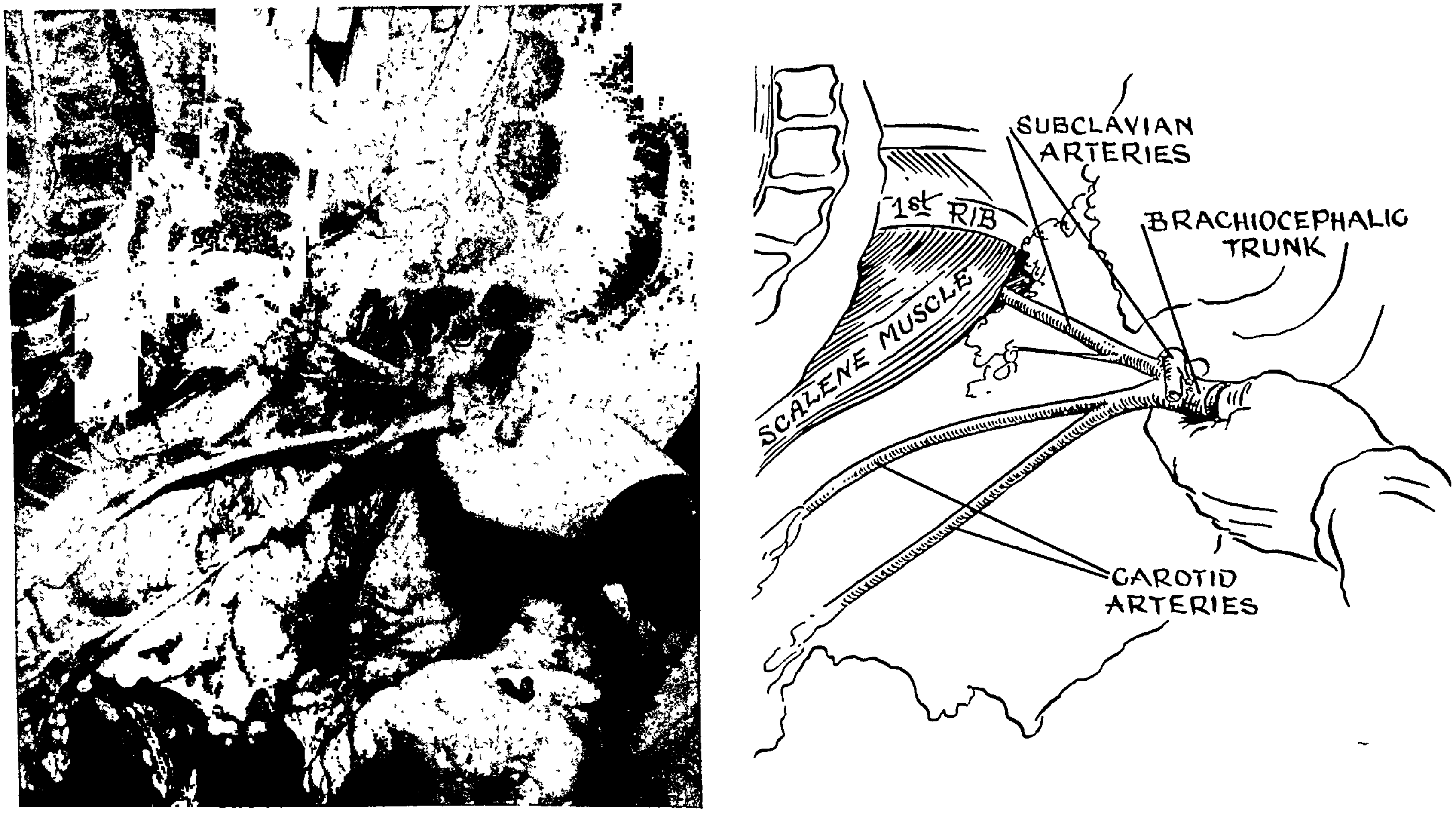

Fig. 1.—Photograph of the inverted left forequarter of a steer showing the method of obtaining subclavian artery branches of adequate length for brachiocephalic shunt purposes. The adjacent line tracing of the pertinent anatomy reveals the relation of the subclavian artery, as it passes into the foreleg, to the angle formed by the anterior border of the scalene muscle and the upper border of the first rib. Incision of the fascia in this angle exposes the subclavian artery which may then be drawn out to the desired length and amputated.

METHODS

Procurement and preparation of the bovine brachiocephalic shunt The procurement of bovine brachiocephalic vessels with intact carotid and subclavian branches is facilitated by a superficial knowledge of the related anatomy and customary slaughterhouse procedure The simple technique to be described ensures intact subclavian and carotid branches of adequate length without mutilation of the carcass or otherwise hampering the work of the abattoir (In our early experience, one of the authors narrowly escaped purchase of four sides of beef for impairing their appearance and salability by excessive axillary dissection in the removal of the subclavian branches)

In selecting a packing house there are obvious advantages in a small government inspected firm where rapport with the management and the government inspector can be established on a personal basis Moreover, where available, a kosher slaughterhouse is to be preferred for the reason that the ceremonial killing involves severance of the carotid vessels at the angle of the jaw, thus preserving maximum length of these vessels In a conventional slaughterhouse the method of bleeding involves the blind insertion of a knife in the suprasternal notch of the stunned animal Incision of the brachiocephalic artery near its origin is intended by this maneuver, but injury of one or more of the carotid and subclavian branches often occurs, rendering the shunt specimen imperfect

According the usual packing house procedure, the killed animal is suspended by its Achilles tendons from an overhead track, skinned, eviscerated, and split into halves This involves four operations (1) removal of the abdominal viscera, (2) removal of the thoracic viscera, (3) splitting the spine to the ligamentum nuchae with a saw and (4) completion of the spine splitting and division of the ligamentum nuchae with a cleaver By requesting the temporary deferment of steps 2 and 4, the surgeon can remove the thoracic viscera with intact shunt vessels without imposing a significant delay in the work of the abattoir A leisurely dissection of the shunt vessels from the thoracic viscera may then be conducted in an area not being used for routine work

Familiarity with the following simple anatomic details will facilitate the expeditious removal of the thoracic viscera and the shunt vessels from the suspended carcass (Fig 1) The bovine brachiocephalic artery trifurcates into two subclavian branches and a short common carotid trunk* The carotid vessels pose no special problem, but the intrathoracic portion of the subclavian vessels is very short due to the narrow thoracic inlet formed by the ring of the first ribs The subclavian artery passes out of the thoracic cavity anterior to the first rib and immediately in front of the scalene muscle mass, unentangled by fibers of the brachial plexus which, in the ox, pass through the body of this muscle A short incision through the fascia anterior to the costal origin of the scalene muscle permits a finger to be hooked about the subclavian artery which can then be drawn out of the foreleg for an adequate length and amputated, without the necessity of an axillary dissection for its removal.

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*The vascular anatomy of the horse is similar but this animal is usually less readily available as a source for shunt vessels

After the shunt vessels have been dissected free of the thoracic viscera, the shunt is fashioned by oversewing the amputated stump of the brachiocephalic artery, converting it into a manifold for the carotid and subclavian

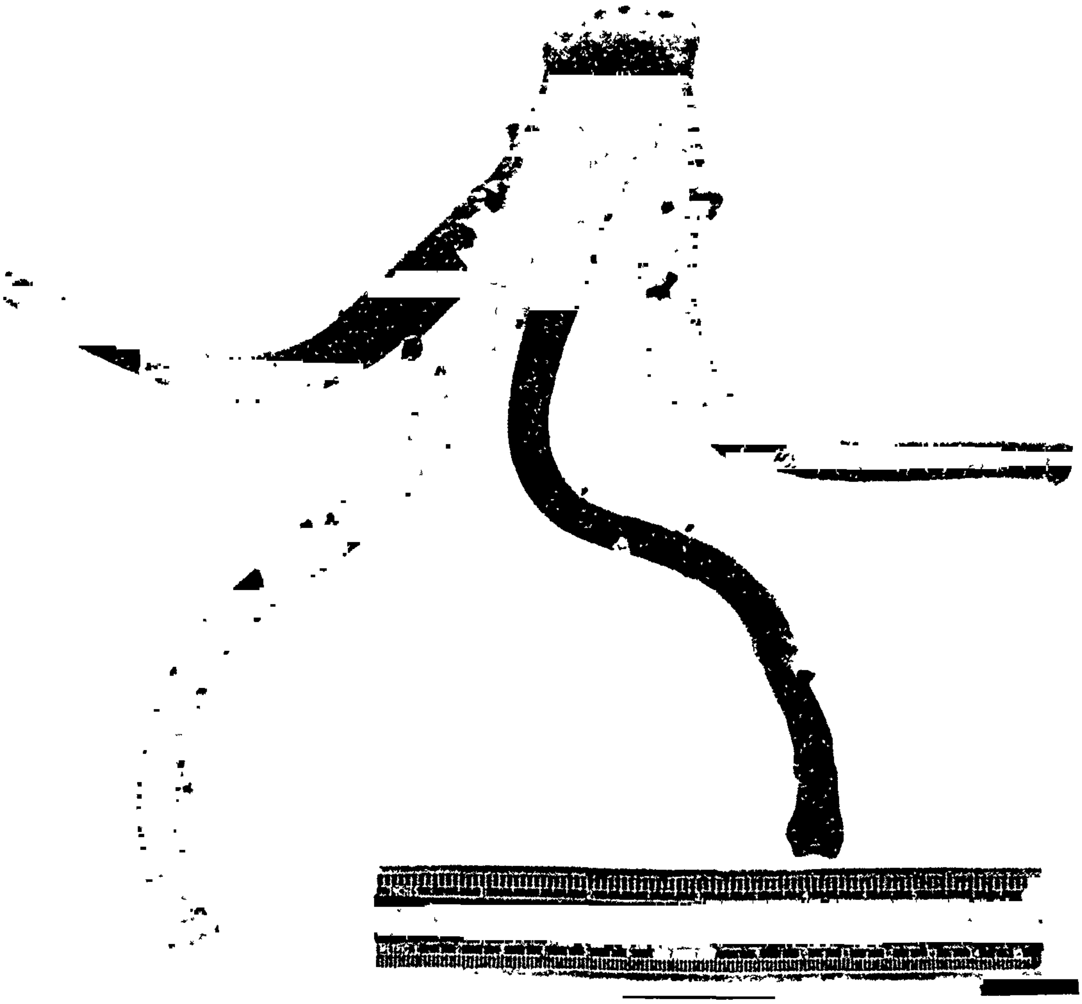


Fig. 2.—A typical bovine brachiocephalic shunt with two carotid and two subclavian artery limbs taken from a 1,000 pound steer is shown. The shunt was fashioned by oversewing the brachiocephalic artery stump as a manifold for the limbs, and all undesirable side branches were ligated and amputated. The shunt is shown in its undistended state.

artery limbs. All undesirable side branches are ligated at their origin and amputated (Fig 2). The average distended diameter and length of the shunt limbs obtained from a 1,000 to 1,200 pound steer are as follows: subclavian artery—16 by 190 mm., and carotid artery—16 by 260 mm.

For experimental purposes the prepared shunts are preserved in the frozen state and a nominal effort at gross decontamination is made by soaking in aqueous Zephiran solution for three hours prior to use. For clinical purposes any of the accepted methods of sterilization and preservation now employed for homografts would be desirable.

Experimental aortic arch resection employing a bovine brachiocephalic shunt and selective hypotension. Adult mongrel dogs were anesthetized with intravenous Nembutal and 100 per cent oxygen administered under intermittent positive pressure through an endotracheal tube. Cannulae inserted into the right femoral artery and vein served for continuous recording of blood pressure by mercury manometer and intravenous drug and fluid administration, respectively. The thorax was entered through the bed of the excised left third rib with the dog in the lateral position and adequate exposure obtained by fracture of the adjacent fourth rib through its neck. The aortic arch and branches were mobilized and the first two or three pairs of intercostal arteries divided.

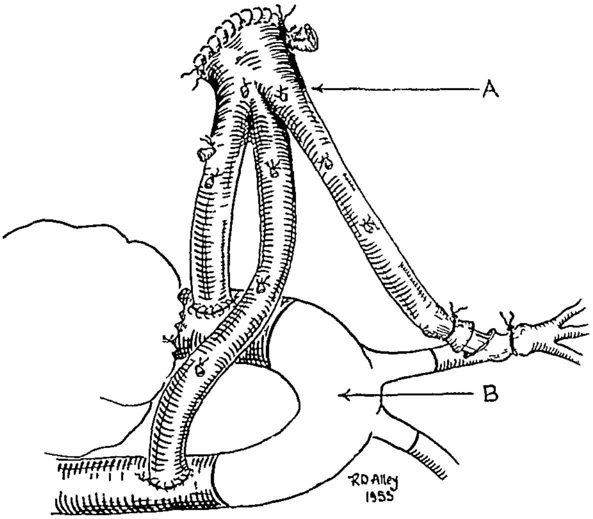
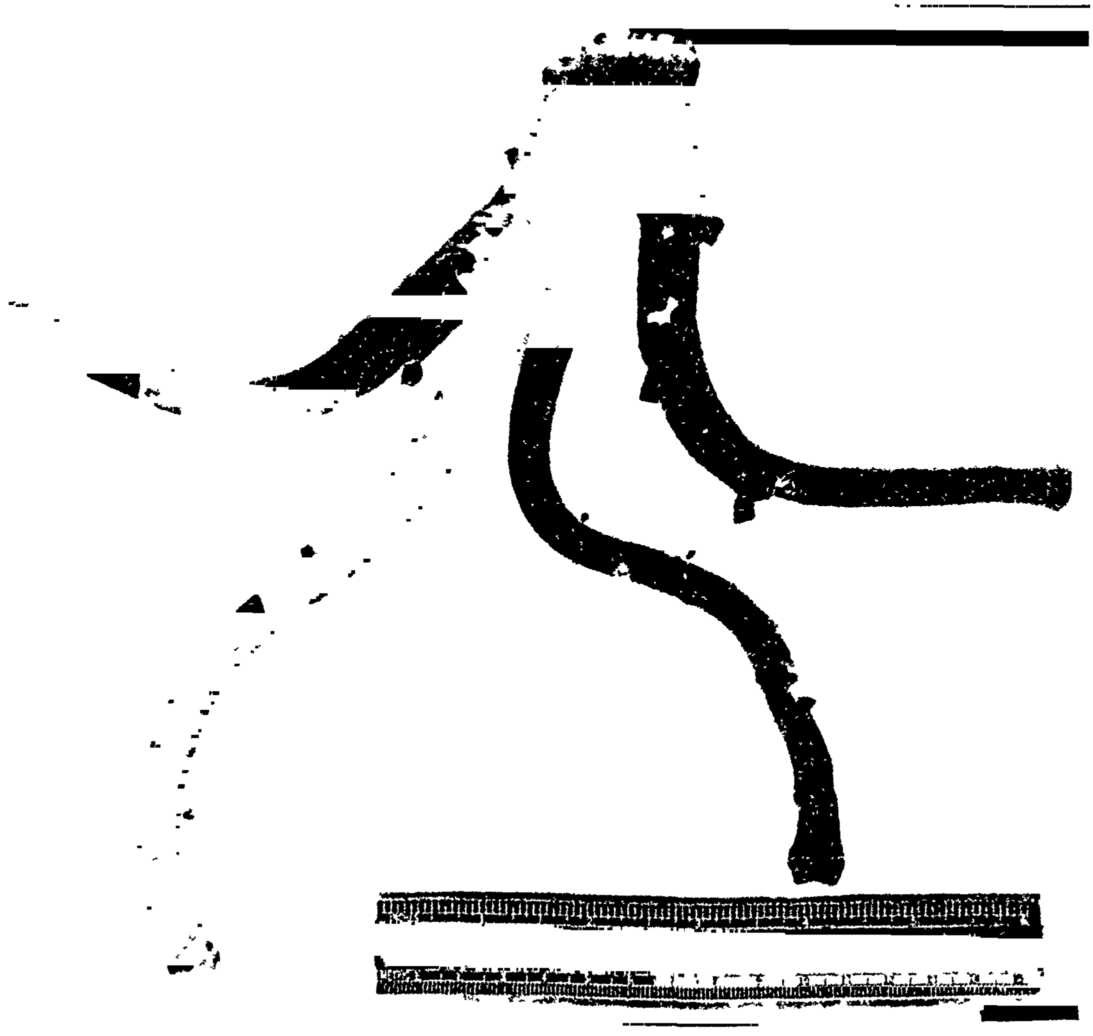


Fig. 3.—*A*, Semidiagrammatic representation of a three limbed bovine brachiocephalic shunt as supplied in experimental aortic arch resection in the dog. The proximal and distal aortic limbs of the shunt are anastomosed to the host vessel by exclusion clamp technique. The dog's brachiocephalic artery is cannulated by the cephalic limb of the shunt. *B*, Area of dog's aortic arch and branches to be resected and replaced by graft.

The aortic arch was then by-passed by means of a three limbed bovine brachiocephalic shunt, in the manner depicted in Fig. 3. With the blood diverted through the shunt the arch was excised and replaced by a graft. Freeze dried, ethylene oxide sterilized homografts or Ivalon sponge prostheses were used to reconstruct the arch except in one instance wherein a formic acid treated braided nylon graft was employed.

the scalene muscle permits a finger to be hooked about the subclavian artery which can then be drawn out of the foreleg for an adequate length and amputated, without the necessity of an axillary dissection for its removal.

After the shunt vessels have been dissected free of the thoracic viscera, the shunt is fashioned by oversewing the amputated stump of the brachiocephalic artery, converting it into a manifold for the carotid and subclavian artery limbs. All undesirable side branches are ligated at their origin and amputated (Fig 2). The average distended diameter and length of the shunt limbs obtained from a 1,000 to 1,200 pound steer are as follows: subclavian artery—16 by 190 mm., and carotid artery—16 by 260 mm.



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For experimental purposes the prepared shunts are preserved in the frozen state and a nominal effort at gross decontamination is made by soaking in aqueous Zephiran solution for three hours prior to use For clinical purposes any of the accepted methods of sterilization and preservation now employed for homografts would be desirable

Experimental aortic arch resection employing a bovine brachiocephalic shunt and selective hypotension Adult mongrel dogs were anesthetized with intravenous Nembutal and 100 per cent oxygen administered under intermittent positive pressure through an endotracheal tube Cannulae inserted into the right femoral artery and vein served for continuous recording of blood pressure by mercury manometer and intravenous drug and fluid administration, respectively The thorax was entered through the bed of the excised left third rib with the dog in the lateral position, and adequate exposure obtained by fracture of the adjacent fourth rib through its neck The aortic arch and branches were mobilized and the first two or three pairs of intercostal arteries divided

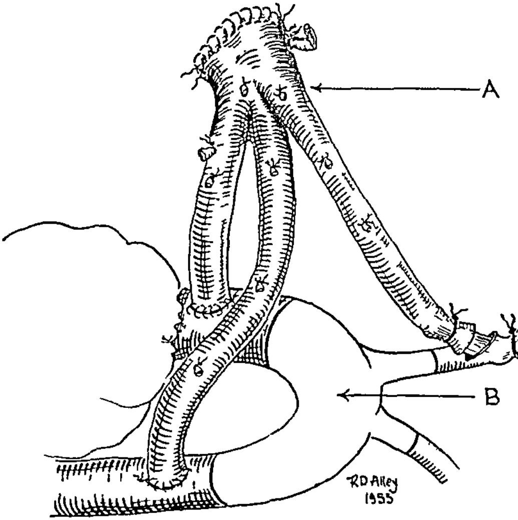

Fig 3—*A* Semidiagramm … e limbed bovine brachiocephalic shunt as supplied in experimen … dog The proximal and distal aortic limbs of the shunt are … l by exclusion clamp technique The dog s brachiocephalic arter … limb of the shunt *I* Area of dog s aortic arch and branches to be resected and replaced by graft

The aortic arch was then by passed by means of a *three limbed bovine* brachiocephalic shunt, in the manner depicted in Fig 3 *With the blood* diverted through the shunt the arch was excised and *replaced by a graft* Freeze dried, ethylene oxide sterilized *homografts or Ivalon sponge prostheses* were used to reconstruct the arch except in one instance *wherein a formic acid* treated braided nylon graft was employed

Arfonad*-induced hypotension was employed during selected steps of the procedure because of the tendency demonstrated in our previously reported series for the proximal aortic shunt anastomosis to disrupt under normal or elevated blood pressures. It is our impression that three factors are responsible for the tendency of disruption at this site:

1. The well-known extreme friability of the ascending portion of the dog's aorta.[5] (An appreciation of the degree of friability of this area can be easily obtained by fracturing the removed specimen transversely with a thumb nail. The longitudinal "grain" splits less readily.)

2. The longitudinal stretch of a portion of vessel contained in a tangential exclusion clamp is a function of the blood pressure present within the vessel when the clamp was applied. This longitudinal tension encourages minute transverse tears at suture line needle puncture sites in the host aorta, thereby weakening the anastomosis.

3. Hypertension induced by the carotid reflex when the dog's brachiocephalic is occluded for insertion or removal of the shunt cephalic limb cannula.

The second and third of these factors can be minimized by inducing hypotension at appropriate times during the procedure as will be described.

Experience has shown that the procedure is best done in the following steps:

1. Mobilization of the arch.

2. Anastomosis of the descending aortic limb of the shunt employing a tangential exclusion clamp technique. The pleura which closely invests the presenting aspect of the descending thoracic aorta is preserved to strengthen the suture line.

3. The systolic blood pressure is then depressed by intravenous administration of a solution of Arfonad containing 0.5 mg. per cubic centimeter until it has fallen to 85 mm. Hg. Experience has shown that the administration of 5 drops or less of the Arfonad solution at a time will safely depress the blood pressure to the desired level without overshooting the mark. As a precaution, however, a solution of Levophed† bitartrate containing .004 mg. per cubic centimeter is kept available as an antagonist for Arfonad overdosage. With the blood pressure at the depressed level, the proximal limb of the shunt is anastomosed to the ascending aorta and the brachiocephalic artery cannulated with the third limb of the shunt. Air is removed from the shunt system by retrograde filling of the proximal and distal aortic shunt limbs first, and then from the cephalic limb in a similar manner, evacuating the air by hypodermic needle. With the shunt in operation the blood pressure is permitted to drift back to normal.

4. The portion of the arch between the shunt limbs and the left subclavian artery are then occluded, the arch excised, and the graft sutured in place.

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*Arfonad—supplied by Hoffmann-La Roche, Inc.

†Levophed—supplied by Winthrop-Stearns.

5 The shunt limbs are then removed in reverse order of their attachment employing Arfonad induced hypotension to 85 mm Hg systolic during the removal of the ascending aortic and cephalic limbs

RESULTS

The aortic arch was by-passed by means of this technique in 24 dogs The period during which the shunt was in actual operation varied from one to five hours (The longest period was occasioned by the necessity of the operating surgeon to interrupt reconstruction of the arch to conduct a clinic) The arch successfully resected and replaced by a graft in 19 of these animals

The elastic properties of the shunt proved to be a great asset in that the shunt limbs could be retracted out of the way to facilitate exposure without threat of kinking Indeed, with shunt limbs of adequate length the manifold could be permitted to rest on the dog's chest wall in any portion of the periphery of the wound The pulsation of the shunt was striking and arouses the speculation that the diastolic ' systole'' of the large shunt manifold may promote coronary filling

Adequacy of blood flow through the shunt was inferred grossly by an absence of demonstrable difference in right femoral artery pressure as measured by mercury manometer in the blood delivered by the shunt alone and by the dog's aortic arch with the shunt excluded

Among the 19 dogs surviving operation only one demonstrated central nervous system damage This animal differed from the rest in that during the occlusion of the dog s brachiocephalic artery for removal of the cephalic limb of the shunt the left subclavian artery was inadvertently left occluded, thereby depriving the brain of aortic arch circulation for a period of ten minutes The dog never regained consciousness and died seven days later Unfortunately, the brain was not examined at autopsy

In all but one instance the shunt remained free of thrombi During this procedure a succession of technical errors with attendant excessive loss of blood led to a prolonged period of profound hypotension ending in death All limbs of the shunt were found occluded by thrombus The shunt employed, however, had been thawed on two separate days and prolonged exposure to room temperature may have induced deleterious changes in its intimal lining which predisposed to thrombosis during hypotension The other four operative deaths were due to technical factors unrelated to the shunt as follows rupture of the host aorta proximal to the shunt due to exclusion clamp fracture of its wall, respirator failure, inadvertent obstruction of the pulmonary artery by traction, and hemorrhagic shock No dogs were lost due to hemorrhage at the shunt implantation sites

A detailed report on the fate of the dogs surviving operation will form the basis for part of a separate study devoted to the behavior of aortic arch grafts In brief, however, 10 of the 19 operative survivors died within the first postoperative day, 5 lived periods varying from three days to five and one half weeks, and 4 are living and well five and one half weeks, six weeks, eleven months, and one year postoperatively, respectively. (The sole long-term survivor of aortic arch resection with homografting of our first series is doing well two and one-half years postoperatively.)

DISCUSSION

The operative mortality in this series of experimental aortic arch resections employing an heterologous vascular shunt in the dog is 20.8 per cent compared with 55.5 per cent in the previously reported series employing a Tygon shunt. Some of the improvement is due to increasing experience as evidenced by the fact that the more experienced team had a mortality of only 10 per cent in the present series.

Five operative deaths in the previous series were due to disruption at the site of the proximal shunt limb implantation on the ascending aorta. The absence of this occurrence in the present series is ascribed to the use of hypotension during certain steps of the procedure, and to a lesser degree to the use of a shunt with elastic properties.

Experience in this series of aortic arch resections has demonstrated the bovine brachiocephalic shunt technique to have the following desirable features: (1) the material is readily available and can be preserved by homograft preservation methods; (2) having the same elastic properties of the vessel it temporarily surplants, there is negligible interference with hemodynamics; (3) its elastic properties and long limbs provide mobility thereby facilitating exposure for grafting; (4) the lining of the shunt is essentially nonthrombogenic if being actively perfused by blood; and (5) the shunt is applied to the aorta employing standard vascular surgical techniques, without the hazard of the critical dexterous maneuver demanded by mechanical coupling methods.[6, 7]

The unhampered exposure permitted by the mobility of the brachiocephalic shunt is an asset not shared by the shunt-graft technique successfully employed experimentally by Satinsky and his co-workers.[8] Bailey's[9] effort to employ this method in a clinical case of large aortic arch aneurysm was largely frustrated by exposure problems imposed by the usual adherence of the pathology to surrounding structures and the presence of the shunt-graft in the field of dissection. The bovine brachiocephalic shunt would appear more promising of practical application in the clinical case.

It is hoped that the detailed description of the method of bovine brachiocephalic shunt procurement and its use in experimental resection of the dog's aortic arch will stimulate others to employ the method in the experimental evaluation of homografts and the various prosthetic materials in the aortic arch location. It might be added that this technique of aortic arch resection involves six separate and different anastomoses and three vascular suture lines which constitute a valuable training excercise for residents interested in vascular surgery.

The authors would like to express their appreciation to Mr. Robert Replogle for skilled technical assistance. We are indebted to the Department of Medical Illustration, Veterans Administration Hospital, Albany, N. Y., for preparation of illustrative material, including the motion picture shown at the Thoracic Surgical Forum.

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AORTIC HOMOGRAFT SUBSTITUTION AND BY-PASS IN SUPERIOR VENA CAVAL OBSTRUCTION

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THE clinical picture of superior vena caval obstruction has been well depicted and discussed in previous articles and discussions in the literature. Many of these, especially the more recent, have been by members of this Association, who have amply referred to articles preceding their own, so that repeated reference is unnecessary except for purposes of pointed discussion.

At the 1954 meeting in Montreal, Scannell and Shaw[1] presented a paper on the relief of superior vena caval obstruction by the use of free vein grafts. We agree with their statement that most cases of superior vena caval obstruction are the result of inoperable malignancy, and we believe now with others that perhaps a number of these can be afforded relief by palliative by-pass, in addition to the use of x-ray therapy. We agree that benign processes causing superior vena caval obstruction should be considered for surgical correction by means of reconstruction of the superior vena cava.

We have had occasion recently to treat one case of benign obstruction of the superior vena cava by resection of the innominate veins and superior vena cava with substitution of an aortic-iliac bifurcation homograft, and to treat 2 cases of malignant obstruction of the superior vena cava by establishing an aortic homograft shunt between the left innominate vein and the right auricular appendage.

CASE REPORTS

CASE 1.—The patient was a 28-year-old man first admitted to Veterans Administration Hospital, Portland, Oregon, on May 12, 1955, with obvious superior vena caval obstruction of two months' duration. He had had a negative survey chest x-ray eight months previously. Blood pressure was 148/90 mm. Hg. Venous pressure was 28 cm. of water. Chest x-rays showed a 3 cm. rounded mass in the right superior hilar area. Angiocardiograms showed constriction of the superior vena cava at its point of origin. Intermediate purified protein derivative was positive and histoplasmin was 4 plus.

On May 24, 1955, the patient was explored via a right posterolateral thoracotomy. The medial aspect of the right upper lobe had to be sharply dissected off a bulging, firm, fixed mass found cephalad to the hilus and anterior to the trachea and encasing the right phrenic nerve and superior vena cava and distal azygos vein and distal innominate veins. The phrenic nerve was dissected free. Biopsies and frozen section "suggested a neurogenic tumor." Following pericardiotomy, about 1 to 1.5 cm. of distal superior vena cava was found uninvolved. The proximal ends of both innominate veins were found uninvolved.

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Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

As the mass was sharply dissected off the trachea the posterior portion of the mass was found to be old calcific, granulomatous, and anthracotic lymph node material. An aortic iliac bifurcation homograft (frozen dried) was then placed upside down as the mass was removed with encased distal innominate veins and proximal superior vena cava. The proximal right innominate vein was anastomosed first to one iliac limb of the homograft, and then the proximal left innominate vein and the distal superior vena cava were clamped and divided and the specimen was removed. The aortic end of the homograft was then anastomosed to the distal superior vena cava stump, the homograft was filled with a dilute heparin solution, the other iliac limb was clamped, and venous return re-established via the right innominate vein and homograft and superior vena cava stump. The third anastomosis was then done. There was immediate improvement on the table of the patient's cyanosis and edema. Postoperative venous pressure was 15 cm. water.

Postoperative angiogram was done two months after operation, but unfortunately only via the left arm. Patency was demonstrated on the left side, and although the patient was clinically fine, the angiogram suggested some narrowing of the lumen of the homograft. Bilateral simultaneous angiograms were done eleven months postoperatively on March 30, 1956, and these demonstrated patency of the graft and perhaps a slight increase in the narrowing of the lumen of the homograft. His venous pressure was 18 cm. of water and he was clinically well. The specimen proved to be a "nonspecific granuloma" densely involving the proximal superior vena cava and distal innominate veins. Because of the impression of the pathologist at the time of frozen section, no portion of the specimen was saved for cultural study or animal inoculation, which might possibly have established a definite etiology.

Case 2.—A man, 53 years old, was a private patient first seen Nov. 3, 1955, with a two weeks' established superior vena caval obstruction preceded by six months of cough. He was having attacks of syncope, and had to sleep upright in a chair. His face, neck, and upper trunk and arms were dusky, suffused, and swollen. There was a wheeze in the right upper chest. X-rays showed a right superior mediastinal mass. Bronchoscopy and aspirate were negative except for evidence of extraluminal tracheal compression. Scalene lymph node biopsy was negative. Left arm angiograms demonstrated complete obstruction of the superior vena cava and probable obstruction of the right innominate vein.

The undiagnosed tumor was explored through a midline sternotomy on Nov. 11, 1955. Involving the pretracheal and paratracheal areas was found a large mass to which the medial aspect of the right lung was densely adherent. The azygos vein was buried in the mass and the superior vena cava was grossly involved by the tumor with extension into the right atrial wall. No separate tumor could be felt in the right lung, but the medial aspect of the right upper lobe was part of the mass just described and a primary bronchogenic carcinoma was suspected. Biopsy of one of the matted confluent lymph nodes showed metastatic carcinoma.

A reconstituted frozen dried aortic homograft was anastomosed to the right auricular appendage following partial amputation. Upon incising the left innominate vein, a thrombus was found in it but with release of the proximal vein the blood flow pushed the firm thrombus out and the homograft was then anastomosed to the side of the left innominate vein. The right innominate vein was proved to be obstructed by tumor involvement proximally.

Immediate satisfactory flow ensued upon removing the clamps and the patient's venous pressure was immediately altered, although the right arm did not immediately improve as much as the left, for the reason just mentioned. The patient was given deep x-ray therapy postoperatively and did very well. He was delighted to be rid of the superior vena caval obstruction and the change objectively was very striking. He was last seen on Feb. 14, 1956 (three months after operation), and was clinically still free of superior vena caval obstruction except for slight prominence of the veins of the right upper chest wall. He was, however, beginning to have some low back pain suggesting metastasis. Recheck x-rays of Feb. 10, 1956, showed some slight decrease in the size of the tumor.

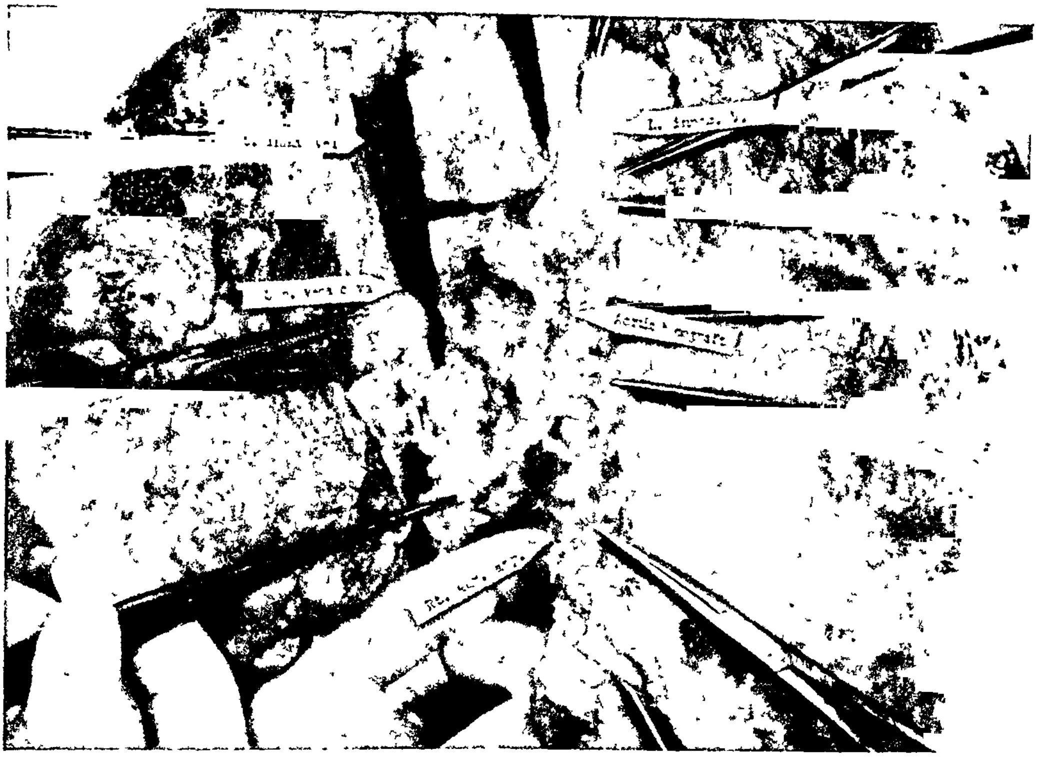


Fig. 1.—Case 2. Aortic homograft shunt—four and one-half months in situ. Graft is wrinkled and irregularly contracted, and there is gross evidence of calcification.

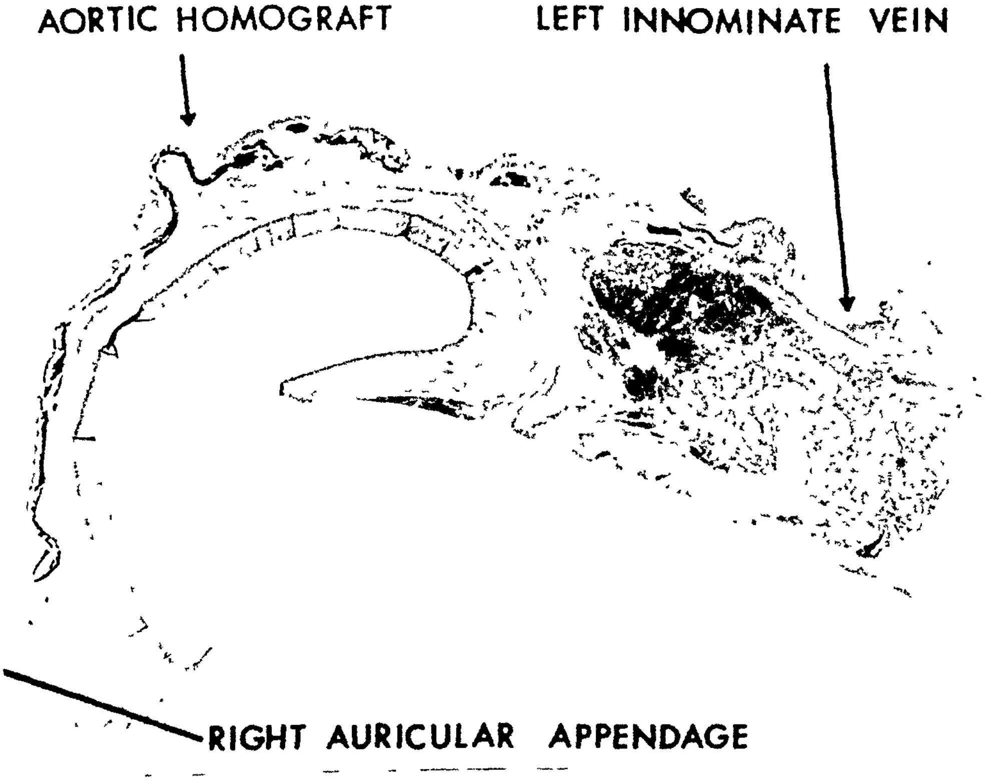


Fig. 2.—Case 2. Calcification in areas of necrosis occurring subintimally and in adjacent media. Thickening of intima by edema and actual fibrous tissue. Condensation and decrease of elastic tissue of media. Patient's own aorta included in this mounted microscopic section.

During the second week in March, 1956, the patient began to fail rapidly, and during this time his home-town doctor noted some slight transient congestion of the patient's face.

He died on March 24, 1956, four and one-half months after operation. Autopsy showed extensive widespread carcinomatosis. The primary tumor, as suspected, was in the medial portion of the right upper lobe, immediately contiguous to the azygos vein and superior vena cava. The superior vena cava and right innominate vein were plugged by tumor. The left innominate vein, homograft, and right auricular appendage were patent, but there had been a striking change in the homograft (Fig. 1). Its wall was wrinkled, sclerotic, contracted, and there were subintimal calcific plaques in it (Fig. 2). Proximally there was a thin veil of mural thrombus. The calcification was in areas of necrosis which had occurred subintimally and in the adjacent portion of the media. The elastic tissue of the media was condensed and decreased as evidenced by elastic tissue stains. The intima was thickened by fibrocellular proliferation. These changes have been described previously by many authors.[2-4] One must consider the possibility that if this man had lived sufficiently long the changes in the homograft might have eventually resulted in obstruction to blood flow.

Case 3.—The patient was a white man who, at age 23 while in the army, had a fibrosarcoma removed from the soft tissues of the right thigh. Three years later, in August, 1948, a small lump was noted in the right groin and he complained of a slight cough. Bilateral resection of the lymph nodes of the groins revealed no evidence of tumor. Chest x-ray showed six metastatic coin lesions in the right lung field. The left side was clear. At this time, I saw the patient and performed a right pneumonectomy on Aug. 24, 1948. The patient was followed at regular intervals during the next six and one-half years *by the Tumor Board of the Veterans Administration Hospital, Portland.*

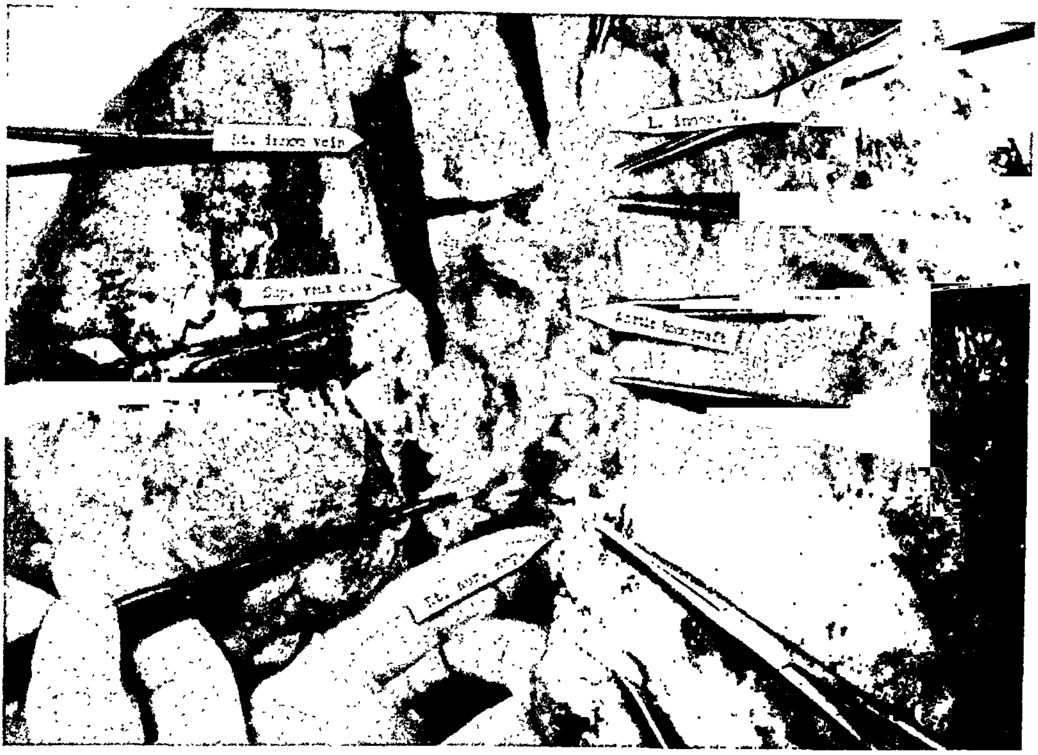
On April 14, 1955, the patient was rechecked and found well except for very slight narrowing of the esophagus on barium swallow. There were no symptoms. Five days later the patient was readmitted because of swelling of the face and hoarseness. There was obvious superior vena caval obstruction and the venous pressure was 31 cm. of water. The vocal cords were not paralyzed. He was discharged by the Tumor Board, but returned in May, 1955, because of increase in symptoms and distress. An angiogram showed what was interpreted as an intrinsic lesion in the superior vena cava at its point of insertion into the right atrium. Venous pressure was 30 cm. of water.

On May 17, 1955, the right chest was explored with the hope of resecting and reanastomosing the superior vena cava. A tremendously thick, tough, solid mass of tissue was encountered. This was largely fibrous tissue on the pleural aspect, and absolutely no *sign of cardiac or other mediastinal* motion was evident. Dissection at various peripheral points failed to identify a pericardial cavity, but masses of tumor were found and identified as recurrent low grade fibrosarcoma. While dissecting posteriorly and laterally in the region of the right atrium, a small hole was made in what seemed to be a heavy layer of tissue, and through this opening there appeared a pulsing flow of tumor tissue and fresh blood clot. It could not be ascertained whether we had opened into a tumor-and-blood-filled posterior pericardial sac or into a tumor-invaded right atrium, and this hole and then the patient's chest were closed.

Surprisingly, the patient's superior vena caval obstruction improved considerably from this exploration, probably due to some degree of decompression, and this has been offered in the past as a form of surgical treatment.[5]

By September, 1955, the Tumor Board reported that clinically the superior vena caval obstruction had disappeared, but *no* venous pressure was recorded.

He was readmitted on Oct. 26, 1955, for consideration of a by-pass procedure. The obstruction had recurred and angiography on Nov. 23, 1955, showed a patent left innominate vein with almost complete obstruction of the superior vena cava. On Nov. 29, 1955, the sternum was split and a shunt was established between the right auricular appendage and the side of the left innominate vein by means of an aortic homograft. Complete relief of the superior vena caval obstruction was obtained.



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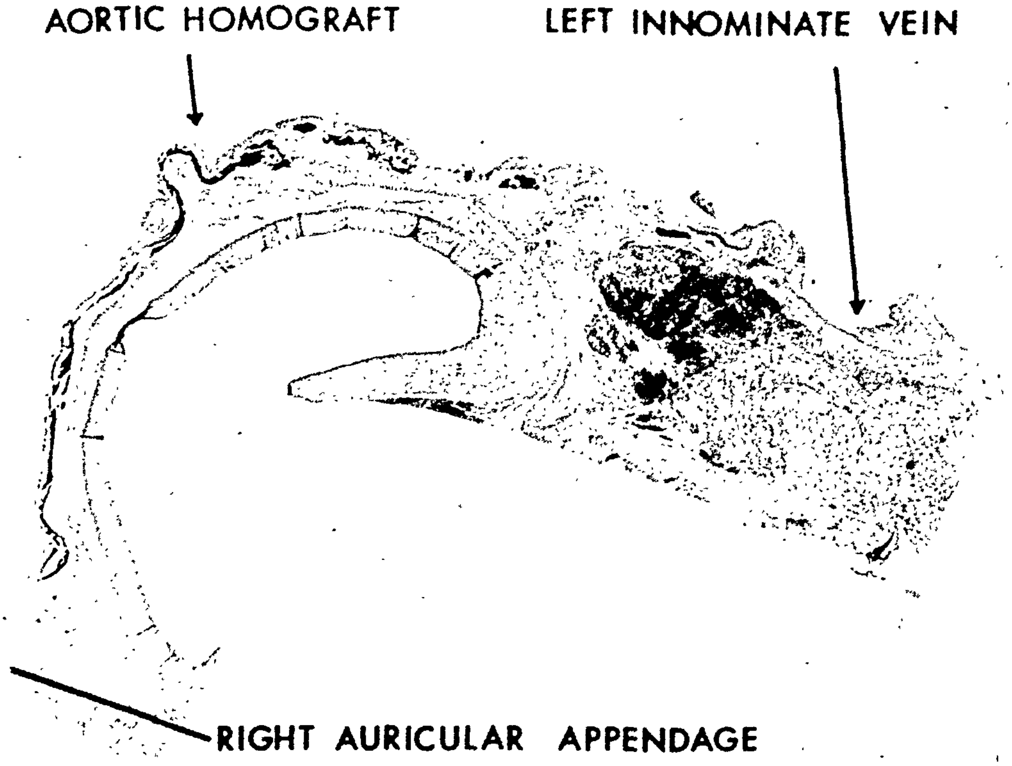

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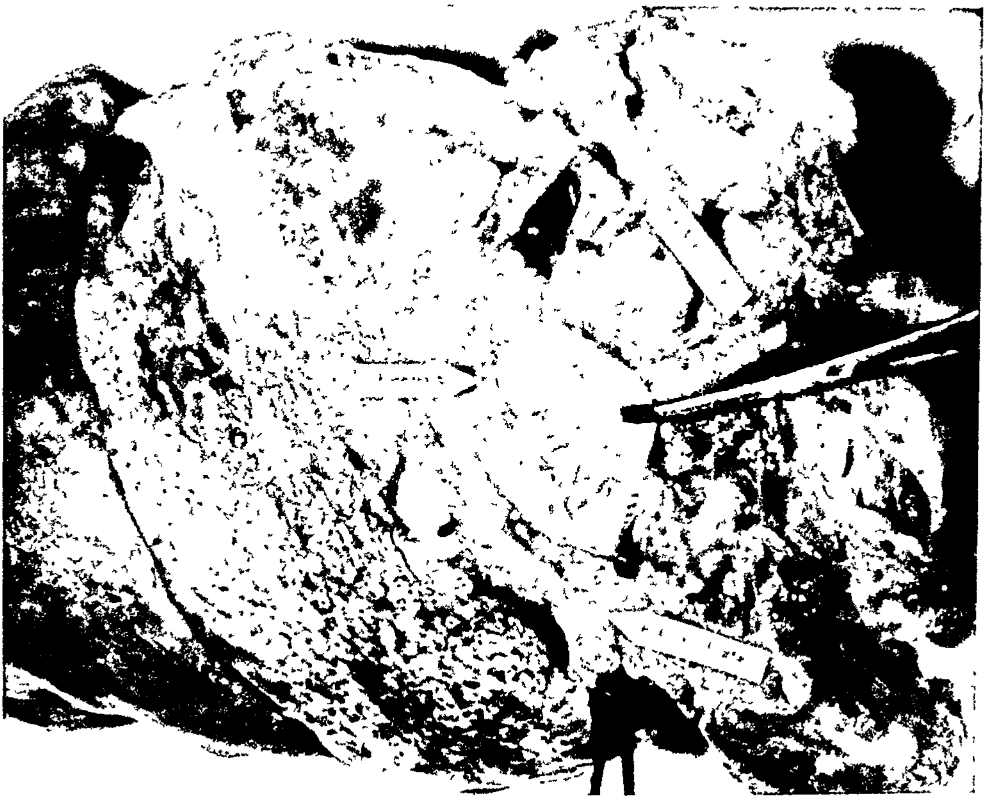


Fig. 3.—Case 3. Aortic homograft shunt—six weeks in situ. Wrinkling of graft grossly.

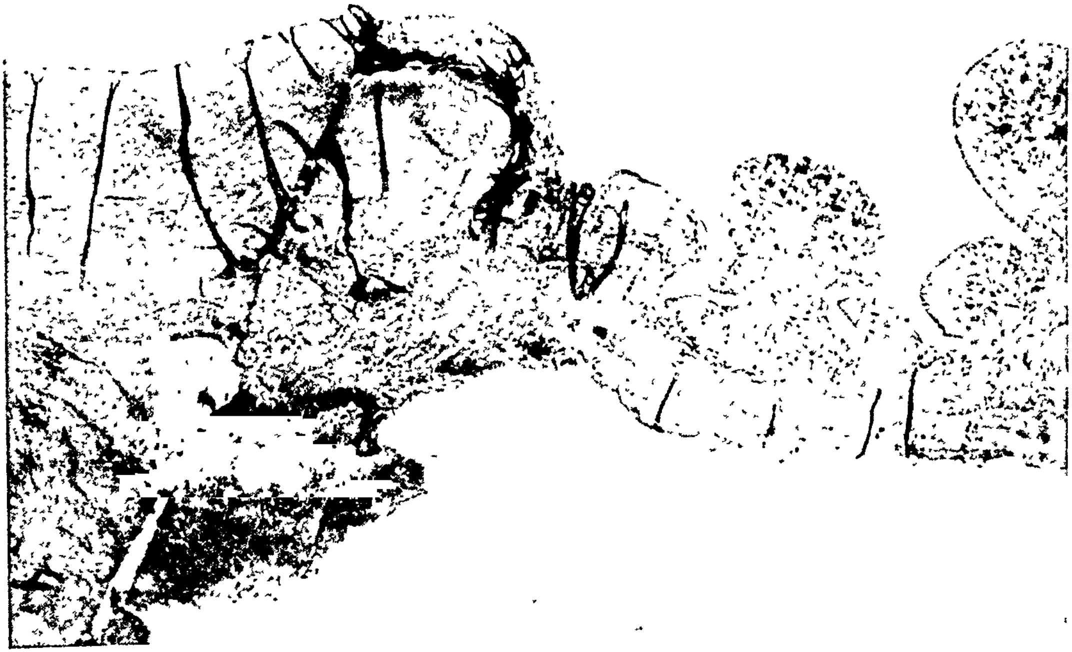


Fig. 4.—Case 3. Aortic homograft—six weeks in situ. No detectable change microscopically except very slight proliferation of fibrous tissue along intima of graft from anastomosis. Graft to left. Auricular appendage on right.

He did well until January, 1956, when he developed dyspnea and a cough Basal rales were noted in the remaining lung He began to have recurrence of his superior vena caval obstruction syndrome and venous pressure on Jan 10, 1956, was 34 cm of water It was thought that the homograft had probably thrombosed, but angiography on Jan 12, 1956, showed the homograft to be patent

The patient died on Jan 14, 1956 (six weeks after the shunt operation), and autopsy showed the innominate vein, homograft, and right auricular appendage to be patent without any evidence of thrombosis (Fig 3)

However, the operative findings of May, 1955, the terminal dyspnea, cough, and rales, and the terminal superior vena caval obstruction syndrome were explained by the finding of huge masses of tumor and old and new blood clot in the posterior pericardial sac, compressing the atria and apparently causing an effectual tamponade with obstruction to blood flow

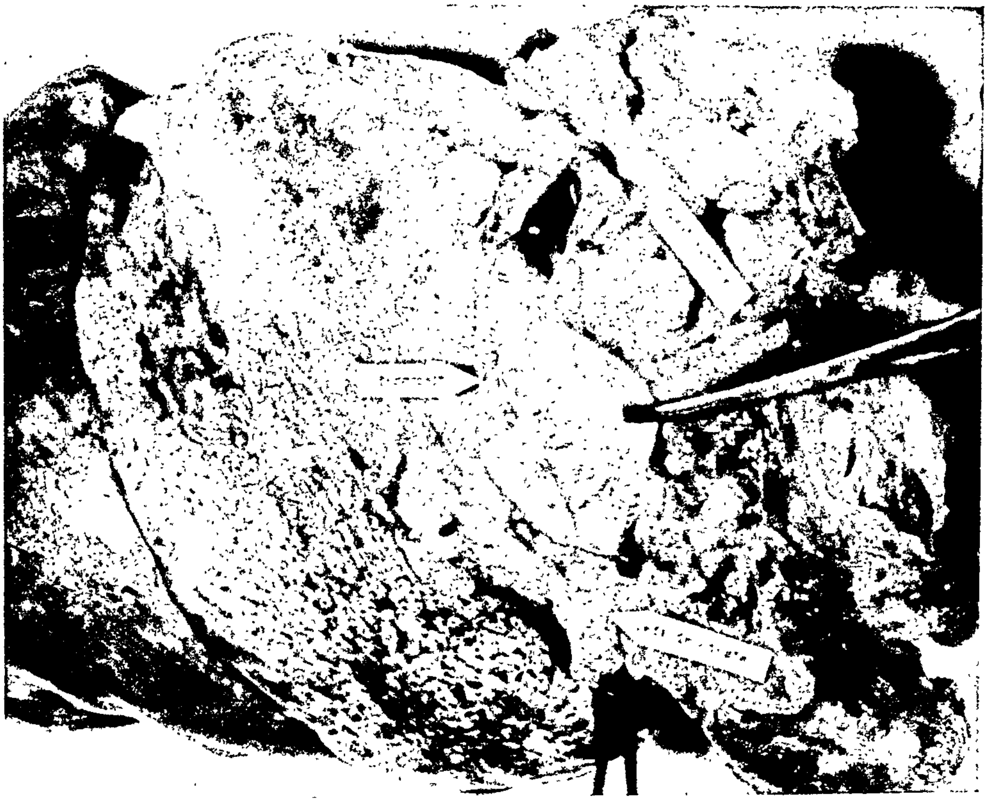
The aortic homograft grossly showed some wrinkling, but microscopically it could not be distinguished from a normal aorta even by means of various stains (Fig 4), but there was some beginning proliferation of fibrous tissue along the intima of the graft from the points of anastomosis

DISCUSSION

The use of aortic homografts as substitutes and shunts in the treatment of arterial disease is well established Their continued use in the treatment of superior vena caval obstruction merits consideration and further trial The discussion of Scannell and Shaw's paper[1] by Samson, O'Neill, Kay, Hanlon, Klassen, Deterling, Gerbode, and Holman, covered the various arguments for and against the use of aortic and venous homografts and autografts It may be that homologous tissues will eventually fibrose or thrombose as Gerbode and Klassen have stated, and the pathologic findings in one and the angiographic findings in another of my cases also suggest this is the fate of these tissues However, Kay's experience would seem to indicate that venous tissues, whether homologous or autogenous, will also fibrose This would seem to leave only autogenous aortic grafts as the hypothetically ideal tissue, and these are not readily available

Insofar as blood vessel replacements generally are concerned, Linton[6] states that homologous arterial grafts thrombose less than other types of grafts, when used in the treatment of arterial disease Of course this thought may not be equally applicable to veins, perhaps for the reason mentioned by Gerbode[1, 6] but Hanlon's,[1] Deterling's,[1] and Holman's[1] experiences with aortic homografts in the treatment of superior vena caval obstruction were favorable, and more recently Reveno, Reynolds, and Dodrill[8] have reported the satisfactory use of an aortic homograft for occlusion of both innominate veins, the patient being well fourteen months after operation

Our own experience recorded here is obviously limited, and the longest follow-up is only eleven and one-half months Moreover, definite gross and microscopic pathologic changes occurred in one homograft in place for four and one-half months, and we do not know what the ultimate fate will be of the aortic iliac bifurcation homograft Nonetheless, our experience has impressed us sufficiently to feel that we should offer this treatment whenever possible, especially as palliation in cases of malignancy The relief of symptoms is dramatic and striking and is gratefully appreciated by the patient



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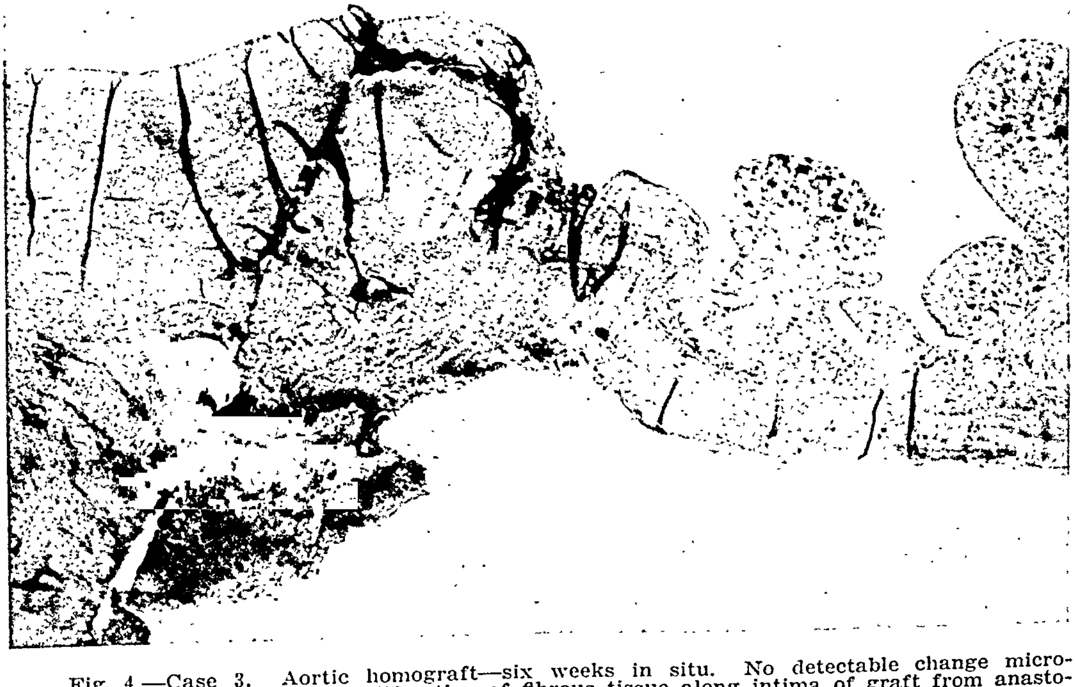

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DISCUSSION

The use of aortic homografts as substitutes and shunts in the treatment of arterial disease is well established Their continued use in the treatment of superior vena caval obstruction merits consideration and further trial The discussion of Scannell and Shaw's paper[1] by Samson, O'Neill, Kay, Hanlon, Klassen, Deterling, Gerbode, and Holman, covered the various arguments for and against the use of aortic and venous homografts and autografts It may be that homologous tissues will eventually fibrose or thrombose as Gerbode and Klassen have stated, and the pathologic findings in one and the angiographic findings in another of my cases also suggest this is the fate of these tissues However, Kay s experience would seem to indicate that venous tissues, whether homologous or autogenous, will also fibrose This would seem to leave only autogenous aortic grafts as the hypothetically ideal tissue, and these are not readily available

Insofar as blood vessel replacements generally are concerned, Linton[6] states that homologous arterial grafts thrombose less than other types of grafts, when used in the treatment of arterial disease Of course this thought may not be equally applicable to veins, perhaps for the reason mentioned by Gerbode,[1, 7] but Hanlon's,[1] Deterling's,[1] and Holman s[1] experiences with aortic homografts in the treatment of superior vena caval obstruction were favorable, and more recently Reveno, Reynolds, and Dodrill[8] have reported the satisfactory use of an aortic homograft for occlusion of both innominate veins, the patient being well fourteen months after operation

Our own experience recorded here is obviously limited, and the longest follow up is only eleven and one half months Moreover, definite gross and microscopic pathologic changes occurred in one homograft in place for four and one half months, and we do not know what the ultimate fate will be of the aortic iliac bifurcation homograft Nonetheless, our experience has impressed us sufficiently to feel that we should offer this treatment whenever possible, especially as palliation in cases of malignancy The relief of symptoms is dramatic and striking and is gratefully appreciated by the patient

It is quite probable that some of the newer plastic materials will prove better and more adaptable and perhaps suffer no changes within the host, but we feel at present that aortic homografts are the best available material for use in the surgical treatment of superior vena caval obstruction either by resection and substitution, or by shunt.

The author wishes to acknowledge gratefully the cooperation and help received by him from D. Altman and B. Stuart, photographers at VAH, Portland, Ore.; to Dr. W. Haug, pathologist at VAH, Portland; and to Dr. M. Heineman and Dr. W. Lehman, pathologists at Good Samaritan Hospital, Portland, Ore.

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EXPERIMENTS WITH SUBSTITUTE ESOPHAGUS

LAURENCE H. RUBENSTEIN, M.D.* (BY INVITATION)
CHICAGO, ILL.

IN THE surgical treatment of esophageal lesions, many occasions occur in which it would be a great advantage to be able to replace easily the diseased portion of the esophagus. In a previous report from our laboratory we described the use of autogenous skin transplants as replacements for portions of esophagus.[1] Many subsequent experiments have been conducted and it seems proper now to report our results.

METHODS

The experiments were all carried out on mongrel dogs.

A. Esophageal transplants with preserved and fresh heterologous homografts: A series of experiments in which segments of thoracic esophagus were resected and replaced by grafts of free donor esophagus from another animal led to the same constant results; namely, failure of new graft to "take" and bridge the defect. One hundred per cent failure was due to lack of healing between the normal esophagus and donor graft esophagus with subsequent leakage and empyema.

B. Skin tube grafts: These series of experiments were previously reported in the Fundamental Forum of The American College of Surgeons (1952). We concluded that autogenous skin, both as a patch graft and as a free skin tube graft, will "take" and bridge the created defect in the esophagus (Fig. 1). The unhappy circumstance which followed was scar formation at the site of the skin tube graft, and strictures with extensive grafts. This, we felt, was a very serious problem. However, if controlled, skin tube grafts would be a real contribution to the field of esophageal surgery.

Substances which might delay and inhibit scar formation were logical things to try in an attempt to stop stricture formation at the operative site.

C. Piromen[2]†: An anti-inflammatory agent was used in five experiments with skin tube grafts. The regime using Piromen was 0.3 c.c. first day, 0.5 c.c. second day, 1.0 c.c. on the third day, and 1.0 c.c. daily thereafter.[3] All our animals died within the first week postoperative with the common finding of no healing of the graft. It could be lifted right out of its bed. We concluded that Piromen inhibits healing and prevents the skin tube from "taking."

From the Department of Gastro-Intestinal Research, Medical Research Institute of Michael Reese Hospital, Chicago, Ill.

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Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

*Department of Surgery (Thoracic), Michael Reese Hospital, Chicago Medical School, Cook County Hospital, Chicago, Ill.

†Supplied by Baxter Laboratories.

D. Reactive tissue tube: It was of great interest to us to note that in some ials where there was an esophageal leak, a reactive *mediastinitis about the* hagus created a firm infiltrative wall. Perhaps, we thought, if a temporary would bridge the gap between the proximal and distal ends of cut hagus long enough to produce a reactive wall, then *a new channel might be*

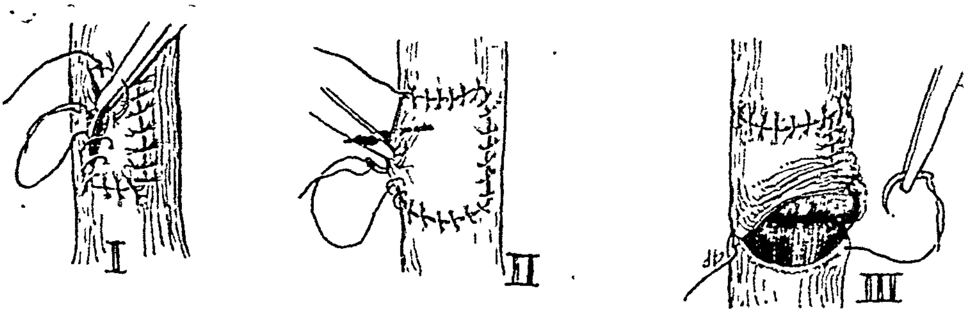

Fig. 1.—Autogenous skin grafts. *I*, Small patch. *II*, Large patch. *III*, Skin tube.

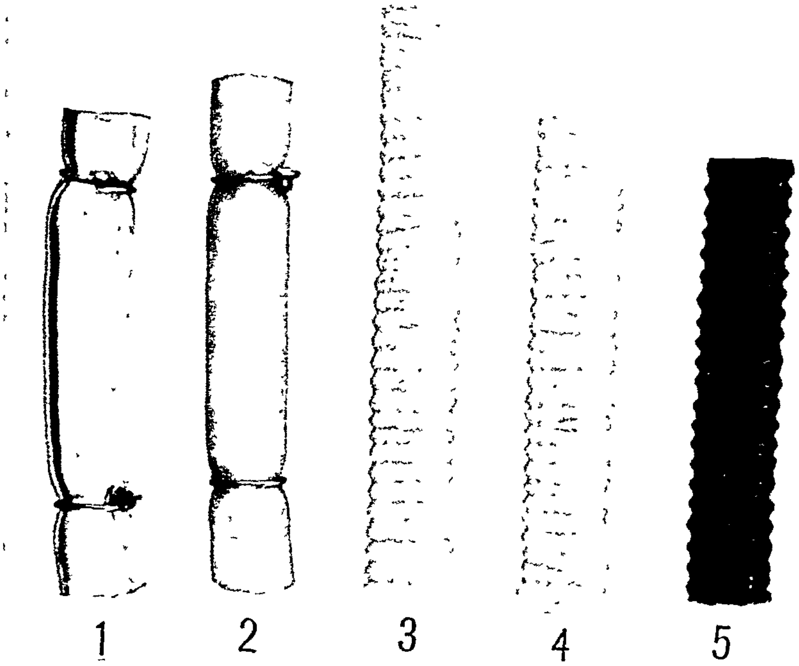

Fig. 2.—Prosthetic esophageal tubes used. *1*, Tygon untreated, nonreactive. *2*, Tygon ed with dicetyl phosphate, reactive. *3*, Crimped nylon tube, untreated. *4*, Crimped nylon sprayed with Krylon. *5*, Crimped nylon tube, shellacked.

ted. Following the suggestion of Berman, a plastic tube (Tygon) was used ie thoracic esophagus.[4] However, in order to produce a severe tissue re- on, the tube was first impregnated with dicetyl phosphate[5] (Fig. 2, No. *2*), a which has been shown to cause severe inflammation with subsequent dense us reaction.

Three experiments were performed in which such an impregnated Tygon was placed in the area of the pulmonary ligament between layers of pleura. In each case within six to eight weeks a thin fibrous tissue tube w formed surrounding the plastic tube. These connective tissue tubes were us to bridge an esophagus defect and all led to fibrous stricture of the lumen wit in two to three weeks.

We knew that the connective tissue tube could be formed and that it coul be used to bridge a defect in the esophagus. However, because of progressiv fibrosis, this viable tube led to a stricture. Therefore, four experiments we done in which *reactive* Tygon tubing bridged the two ends of esophagus. Th tubes were held in place by simple circumferential ties about the proximal an distal ends of the esophagus (Fig. 3, *A*). The stiff tube was to act as a suppo

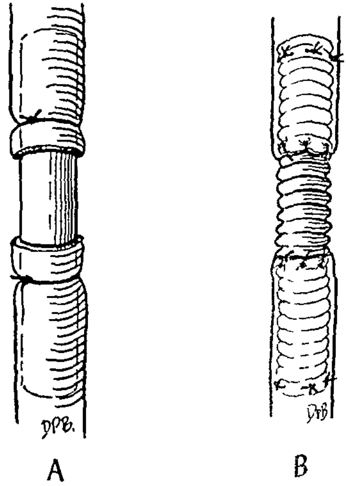

Fig. 3.—Sketch of technique used to bridge esophageal defects. *A*, Tygon tube held in place b circumferential ties. *B*, Crimped nylon tube held in place by interrupted stitches.

while a new connective tissue tube was forming about it. Our main proble encountered here was that the tube slipped. One dog lived four months be fore the tube slipped into the stomach. Within one week severe stenosis of th lumen followed. The other dog vomited the tube. In each case, strictur quickly ensued. Dilatations with graduated Hurst dilators were carried ou successfully for two weeks on one dog. Through an error, subsequent dilatations were not done and again irreversible stenosis followed.

E. Crimped nylon tube prosthesis: The problem of better anchoring prosthetic tube led us to try a crimped nylon tube.[6] (These tubes were describe as vascular conduits by Edwards and Tapp.*) The advantage of the tube wa its ability to take stitches and its semirigid flexibility. At first inspection i was seen that the tubes were not watertight and when moistened they were no firm. We therefore decided to stiffen and waterproof the tubes by two methods: (1) a water repellent spray (DuPont Krylon) was sprayed over the entire surface (see Fig. 2, No. *4*), and (2) the tube was placed in common shellac used in the physiology laboratory (see Fig. 2, No. *3*).

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*We are obliged to Dr. J. S. Tapp of the Chemstrand Corporation for supply of thes tubes.

TECHNIQUE

The experiments were divided into replacement of segments of resected esophagus in two locations—the cervical esophagus and the thoracic esophagus. The technique for placing the tubes (see Fig. 3, *B*) was as follows: A 2-inch segment of esophagus was resected. Because of the elasticity of the organ, the gap between the proximal and distal ends was sometimes 3 inches. The nylon crimped prosthetic tube was inserted to bridge the defect. A general rule which we learned was that the portion of tubing which is to be inserted into the lumen of the esophagus must be the same length as the defect itself. That is, if the bridged area is 2 inches, then the portion of tube in the proximal and distal esophagus should be about 2 inches each. Hence, to bridge a 2- to 3-inch defect, the tube should be 6 to 8 inches long. Four to six interrupted cotton sutures are placed through the esophagus at each of the ends of the tube. This anchors the tube. The margins of cut esophagus are then sutured with interrupted stitches to the nylon tube. It is best to be able to pleuralize this area, if the mediastinal pleura is available. Care should be taken in the dissection of the esophagus to preserve its segmental blood supply.

Seven animals were operated on intrathoracically. Two dogs died of leakage and empyema in the first week postoperative. Two died of distemper within the first week postoperative, but the surgical site was intact. Three animals ate well for three to five weeks and then developed swallowing difficulties. In all the animals, the tube slipped out of the esophagus and into the stomach and, as in previous experiments, the new esophagus shrunk and strictured. It has always been our belief that these constricted areas could be dilated if they are recognized early enough. Because tubes slipped into the stomach without producing symptoms until the stricture of the esophagus was advanced, we decided to place the tubes in the cervical esophagus expecting the animal to vomit the tube when it became loose. Soon after the tube was vomited, dilatations could begin.

The cervical esophagus was exposed, and 1½- to 2-inch segments were removed. The defect was bridged as previously described. The dogs were placed on a rigid regime of nothing by mouth for seven days, atropine 7 mg., three times a day, to dry secretions, and intravenous fluids. This relatively simple procedure was successful in 5 dogs, who survived. In four to five weeks the tube was vomited and the new portion of esophagus began to contract. Dilatations can be successfully carried out if started early and maintained, first at daily, then at weekly intervals. For example (Dog No. 5413), the nylon tube was placed in the cervical esophagus. One week postoperatively the dog was eating well. A barium swallow three weeks later showed good swallowing, no obstruction, the prosthesis still in place. In four weeks the tube

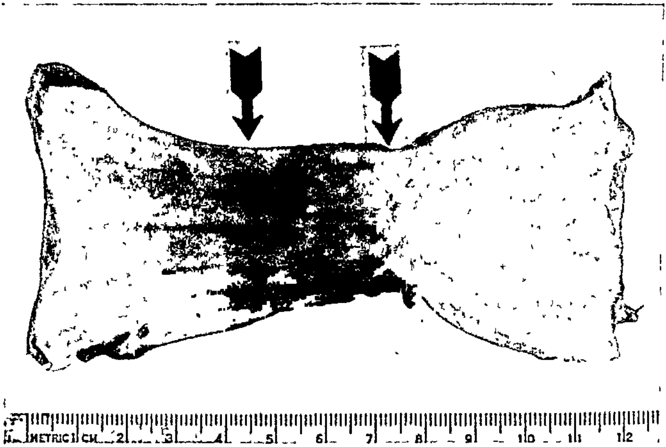

Fig. 4.—Dog No 5413. Eight weeks postoperative sacrificed specimen. Area of substitute esophagus between arrows. Lumen adequately maintained by dilatations.

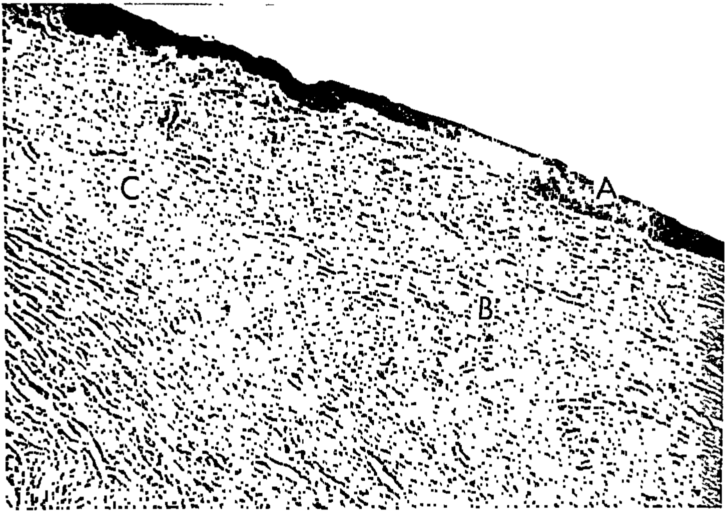

Fig. 5—Microsection of specimen Fig. 4. *A*, Squamous-cell epithelium. *B*, Fibrous tissue wall of new esophagus *C*, Normal esophagus.

was vomited. Progressive narrowing of the esophagus was noted on barium swallow so that five weeks postoperatively (one week after the tube was vomited), evidence of obstruction was seen on fluoroscopy. Dilatations were immediately started with Hurst mercury filled dilators on the unanesthetized animals. The lumen was easily stretched to No. 40 size, about the size of a thumb (Fig. 4). Eight weeks postoperatively, the animal was sacrificed. The new esophagus was lined with squamous-cell epithelium (Fig. 5). After dilatations the lumen is the size of a thumb (2.5 cm. in diameter).

DISCUSSION

It is evident that a new substitute esophagus can be created as was outlined. This new tube, however, has deficiencies. Namely, (1) it is not covered with muscle and it is not innervated, so that peristalsis is impaired, and (2) much more serious is the unfailing tendency of this structure to scar and contract. In the cervical esophagus, where the effort of deglutition is strong, the bolus is well propelled beyond the site of peristaltic absence. In the thoracic esophagus the bolus slowly passes through the operated site. The scarring and stricture can be controlled by use of dilators at frequent intervals. In the human being, who chews his food well, can complain of any early dysphagia, and who could cooperate, it is conceivable that this technique would be feasible, if associated with frequent dilatations.

It would seem that, if some technique could be developed which would prevent the stricture and scarring of the new tissue, the most serious handicap of this procedure would be eliminated. Another definite contribution (but perhaps not as favorable) would be to be able to place a prosthesis which would not leak and would not wander from its site.

Our experiments are proceeding in the two directions. We hope to be able to report further results.

CONCLUSIONS

1. Our experiences with substitute esophagus are related.
2. Substitute esophagus can be created.
3. The substitute esophagi created in the cervical esophagus are more successful and more easily maintained.
4. Stricture formation remains a major problem in the new tissue.

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DISCUSSION

THORACIC SURGERY FORUM PAPERS

DR ALFRED GOLDMAN, Beverly Hills, Calif —I wish to direct my remarks to Paper No 16, which has in it the problem of the acute pulmonary artery and right sided heart occlusion, and I wish to demonstrate the physiologic effects of right sided heart occlusion by occluding the pulmonary artery, with some observations we have made in a study of cinematography at the City of Hope Medical Center with Drs Zeutlin, Rigler, Rehman, and Gyarfas This work has so far been done only on dogs In the course of these studies some observations have been made which shed light on what may happen after acute pulmonary artery occlusion When the common pulmonary artery is occluded by a clamp, the right ventricle is seen to dilate, to increase its size, and the beat to become somewhat more feeble If one is able to visualize what is going on within the right ventricular cavity, one sees that there is immediate dilatation of the atrioventricular valve, it becomes insufficient and there is a reflux of blood back into the venae cavae, and this is demonstrated in the movie If one changes from a contrast medium such as Urokon or Diodrast to a contrast medium of a gaseous type, one can further study this problem When this is done, if a mixture of helium and oxygen is used, injected at the rate of about 500 c c in less than two seconds, then the myocardium of the right ventricle appears different, it not only becomes markedly dilated, but also becomes red instead of cyanotic There is no evidence of foaming within the right ventricle

Motion picture—cinefluorography with electrocardiogram

The right ventricle is cannulated and the dye will be injected into the right ventricle directly The clamp is on the pulmonary artery, and you see the reflux, which has occurred through the insufficiency of the atrioventricular valve, opacifying both the superior and inferior venae cavae, with each ventricular systole This of course is a visual demonstration of what we expect will happen

After injecting helium 20 per cent and oxygen 80 per cent, the heart beats on as evidenced by the electrocardiogram No foaming appears to occur although classically we think it should when there are large amounts of air in the right side of the heart After five minutes the right heart has nearly filled with blood The right ventricle is a deep red color, redder than the left, and apparently derives some oxygenation from the oxygen helium mixture In another two minutes there is more blood and less gas, and after another injection there is actually some air reflux back through the tricuspid valve into the venae cavae You can see the chordae tendineae, the valve action, and the dilated ring After seven minutes no electrical changes occur and the heart is pumping regularly and all the gas has disappeared

DR H HANSON, Stockholm, Sweden —This discussion was not returned EDITOR

MR DENNIS MELROSE, London, England —This discussion was not returned EDITOR

DR EARLE B KAY, Cleveland, Ohio —As you have gathered this morning, one is not considered very sociable in Cleveland unless he has a pump oxygenator I would like to describe the one Dr Cross and I developed during the past year and to mention our technique for closure of ventricular septal defects

(Slide) We have developed a rotating disc oxygenator-reservoir. It requires a minimum priming of 800 c.c. of blood but an optimum of 1,400 c.c. is used. The additional 600 c.c. act as a reservoir. Two sizes of oxygenators are used. One contains 60 and the other 100 Teflon discs. The smaller oxygenator has a capacity of 2,000 c.c. blood flow per minute and the larger has a capacity of 4,000 c.c. per minute. As the discs revolve, a thin film of blood is exposed to the oxygen in the upper part of the chamber.

(Slide) We have operated upon 17 patients with three deaths. There has been only one death in the last 11 patients, and that was a child with a severely malformed heart for which nothing could be done. We have utilized blood flows ranging from 40 to 80 c.c. per kilogram per minute, the majority having been between 60 to 70 c.c. per kilogram per minute. Flow rates have been dependent upon venous return and mean arterial pressure. Arterial oxygen saturations have varied from 97 to 103 volumes per cent. The average increase in hemolysis in the 17 patients was 32 mg. per cent. There was no significant trauma to the blood elements except for a slight fall in the platelet count as determined by phase microscopy. There was no bleeding tendency postoperatively. The average postoperative clotting time was seven minutes, which became normal within one or two hours. Cardiac by-pass times have ranged from fourteen to forty-five minutes.

Though hemolysis has not been a problem with the use of a Sigmamotor pump, experimentally we have found that this can be even further reduced by means of a hydraulic pump which compresses a large valved rubber tube through a fluid medium. This pump as demonstrated on the slide has a capacity ranging from 200 to 4,500 c.c. per minute.

(Slide) This is a photograph taken during closure of a large ventricular septal defect. If the sides of large defects are approximated by direct suture, there is a tendency for such sutures to pull out. Consequently, we utilize a plug of Ivalon sponge with multiple interrupted sutures. Since using this technique we have had only one patient who has had a murmur postoperatively. There have been no bundle branch blocks afterward. We feel that there is a certain advantage in maintaining the normal heartbeat (at least for most of the time) rather than stopping the heart, for it maintains a well-oxygenated myocardium; there has been no instance of ventricular fibrillation; it allows blood to escape through openings not completely closed so that additional sutures can be employed; and the flow of bright red blood will make other possible septal defects obvious. In 3 patients, multiple septal defects were present.

DR. DENTON A. COOLEY, Houston, Texas.—Our experience with extracorporeal circulation to the present time is limited to 6 patients with four survivors. The two deaths occurred in extremely sick infants with atrioventricular communis defects, one of which was probably completely uncorrectable. Four other cases of interventricular septal defects have all survived with gratifying results.

Our method of cardiac by-pass is similar to that described by Drs. DeWall, Read, and their associates with a bubble oxygenator and employing the reduced flow principle. Our heart-lung machine was constructed by Dr. Benjamin Belmonte.

Our experience is somewhat unique in that the survivors were all adults or adult-sized adolescents, and flow rates between 1,800 and 2,600 c.c. per minute were employed in an attempt to provide 40 c.c. per kilogram body weight per minute. Plasma hemoglobin in the oxygenated blood at the completion of the perfusion has not exceeded 50 mg. per cent and no ill effects have been demonstrated from hemolysis. Perhaps Dr. DeWall would comment on his own observations on hemolysis and other results of trauma to blood resulting from turbulence in the bubble oxygenator.

Unlike almost all other groups engaged in this type of work we have not used protamine to neutralize heparin following the perfusion and have observed no abnormal bleeding after operation. We have injected 1.2 mg. heparin per kilogram body weight just prior to the cannulation and the blood used for priming the oxygenator and pump contains 18 mg. heparin for each 500 c.c. blood. We have not used protamine because in 2 of our early patients slow injections of even small amounts appeared to produce hypotension and we decided to determine the necessity for this drug after cardiac by pass

DR WATTS R WEBB, Jackson, Miss —Many of the papers this morning have dealt with the dangers of ventricular fibrillation and various methods of controlling it or at least modifying it This brings to mind that the exact mechanism of ventricular fibrillation is as yet incompletely understood, even though we do know many of the factors that help to control it It is still highly debatable among cardiologists and physiologists whether it arises from a multifocal or from a unifocal site as a circus movement type of procedure We have seen this morning that it can be regulated by many extraneous influences—drugs, electrolytes, and hormones We have also heard from Dr Shumacker's group that it can be regulated by factors influencing the auricular conduction system, that is, by blockade of the sinoauricular node and by dorsal sympathectomy We have been blocking the atrio ventricular node, either with procaine or by actually severing the conduction bundle in the region of the node We have found that after either method with complete dissociation of the auricles and ventricles, it is quite difficult to produce fibrillation in the ventricle by an electric stimulus or by focal cooling The exact significance of this remains uncertain It seems to argue against the mechanism of ventricular fibrillation, from these types of stimuli at least, being due to a circus movement It is believed that this will give us one more approach for studying the mechanisms and control of ventricular fibrillation

DR E S HURWITT, Scarsdale, N Y —I should like to comment briefly on Paper No 18, in which Dr Watkins demonstrated so nicely that myocardial irritability in hypothermic and normothermic dogs can be suppressed by the hormone like preparation, somatotrophin We were supplied with some of this drug, which was evaluated by the members of our anesthesiology department at the Montefiore Hospital in a group of normothermic human beings Twenty five noncardiac patients in regular sinus rhythm were prepared with this drug as Dr Watkins described for the dog, given some twelve hours before and four hours before anesthesia The myocardial irritability was registered by continuous electrocardiography during intratracheal intubation Approximately one third of these patients demonstrated substantial evidence of myocardial irritability during intratracheal intubation This was compared with a control group of patients prepared in exactly the same way, premedicated in the same way but without somatotrophin One third of these patients also demonstrated substantial myocardial irritability It was therefore our conclusion that in the normothermic human being, somatotrophin has no significant effect on suppressing myocardial irritability

DR CLARENCE W LILLEHEI, Minneapolis, Minn —In relationship to Dr DeWall's presentation, the biochemical and physiologic responses in these first 80 patients to undergo total by pass, utilizing the bubble oxygenator, have been studied in detail in order to acquire, if possible, a working knowledge of the numerous features unique to this field of surgery, since it has been readily apparent to us for some time that progress in this field of cardiac surgery has become possible largely through increased knowledge of physiologic mechanisms

To date, at the University of Minnesota Hospitals, 144 patients have undergone a total by pass procedure for various types of intracardiac lesions These perfusions were performed by means of controlled cross circulation (45 patients), the arterial reservoir (5 patients), the biologic (dog lung) oxygenator (14 patients), and the artificial (bubble) oxygenator This bubble type oxygenator, consisting of a simple disposable unit sterilized by autoclaving, has been utilized for the last 80 intracardiac operations in infants, children, and adults It is our expectation based upon this experience that this simple and efficient type of pump oxygenator will accelerate the wide application of open intracardiac surgery in a manner comparable to the way in which the endotracheal tube accelerated the development of intrathoracic surgery

After the initial learning phases of these operations, both the results and the risks of open heart surgery appear most closely related to certain patient factors This will be brought out in a moment in the summary of our results with closure of ventricular septal defects

Five, repeat, five copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 600 South Kingshighway, St. Louis 10, Missouri.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. Karl P. Klassen, The Ohio State University, Columbus 10, Ohio, before Dec. 15, 1956.

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions. If the films are well labeled, it will not be necessary for the author to be present for comment.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec. 15, 1956, otherwise the application will be deferred for consideration until the 1958 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. O. T. Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn.

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year. The new letters of recommendation should also be sent to Dr. Clagett, the Chairman of the Membership Committee.

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Original Communications

TRACHEAL RECONSTRUCTION

John M. Keshishian, M.D.* (by invitation), Brian Blades, M.D.,*
Washington, D. C., and Edward J. Beattie, Jr., M.D.,**
Chicago, Ill.

GLUCK and Zeller[1] are credited with the first investigations concerning tracheal reconstruction. The tracheal rings of dogs were severed and anastomosed successfully. In 1884,[1] Kuester removed a stricture of the human trachea and repaired the defect successfully. During the latter part of the nineteenth and early twentieth centuries, secondary closure of tracheostomies was often required in patients who had survived diphtheria and required tracheostomy as a lifesaving measure.[1] Various methods were utilized, fascia or skin flaps were often used, as well as supporting cartilaginous grafts and metallic prostheses.

It has been established that in most cases early approximation of an incised trachea will be successful. Nach and Rothman describe primary suture of the trachea after knife wounds with satisfactory results. Successful reanastomosis of the cervical trachea, after division and resection in dogs, has been recorded by Maisel and Dingwall.[3] In some instances, segments as large as 2.5 cm. were removed. In a series of 12 animals, there was one instance of postoperative stenosis. Ferguson and his associates,[1] in the study of primary tracheal anastomosis, concluded that when stenosis, following repair, did not exceed one third of the original lumen, there were no distressing symptoms. If, however, the stenosis occluded the trachea to one fourth of its normal circumference, stridor and respiratory infection would follow.

Large defects of the trachea, involving substantial loss of tissue, sometimes preclude primary end-to-end anastomosis. Ferguson found that in dogs, if

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Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

*From the Department of Surgery, The George Washington University School of Medicine, Washington, D. C.

**From the Department of Surgery, the Presbyterian Hospital of the City of Chicago and the University of Illinois College of Medicine (Rush).

tension was sustained on the severed ends, some length could be added, particularly if the procedure was done in stages. This technique, however, does not appear to be applicable in the human being.

The feasibility of primary suture of the trachea or bronchi has been established both experimentally and by clinical experience. The contributions of Paulson and Shaw,[4] Abbott[5] and Bikfalvi[6] and their co-workers, in excising stenosed portions of the tracheobronchial tree and reanastomosing to conserve lung tissue, have been of great importance. Scott's[7] case of primary suture of the trachea, following laceration by a broken windshield, is important since the patient was living and well three years after surgical repair and, although the trachea had been completely severed, there was no abolition of the cough reflex.

Large tracheal defects with circumferential loss of tissue present a more difficult problem and must be repaired with some material which will be airtight, semirigid, and not be rejected by the body. Combinations of cartilage, skin grafts, and fascia have been used successfully in small defects but are rarely adequate when the defect is large.

Gebauer[8] has made many important contributions in the use of reinforced dermal grafts to replace small stenotic lesions of the membranous portion of the bronchus. Penton and Brantigan[9] have employed viable pedicle flaps to cover larger defects, and Gibbon[10] has used a portion of costal cartilage wrapped in pleura for the same purpose.

A great variety of prostheses have been studied for the repair of tracheal defects. Daniel's[11] investigations proved that tubes of Vitallium, stainless steel, and glass would temporarily provide an airway. Longmire[12] has reported the use of a Lucite tube joined to the tracheostomy tube. This prosthesis was removed ten and one half months later. The airway did not remain patent, however, and it was necessary to reinsert the prosthesis for an additional six months. Jarvis[13] describes the use of a stainless steel tube after resection of the trachea for a cylindroma. The tube remained clean and patent for eighteen months, but the patient died from massive metastases. Clagett[14] has studied the use of polyethylene tubes as an airway over which the resected ends of trachea or bronchus were anastomosed. This procedure, in general, was unsatisfactory. One of the great difficulties was the loss of the cough reflex (Tables I and II).

Bucher and co-workers,[15] Belsey,[16] Rob and Bateman,[17] and Edgerton[18] have investigated the feasibility of metallic meshes for tracheal reconstruction. Belsey has also studied the use of a wire coil wrapped with host tissue, for tracheal and bronchial replacement.

Accumulated data on these investigations and our own experiences indicate that if it is necessary to use a prosthesis, the metallic meshes have certain distinct advantages.

These materials have enough rigidity to maintain the curvature, arc, and lumen necessary for tracheal reconstruction, but do not have the disadvantages

TABLE I

AUTHOR	YEAR	PROCEDURE	RESULTS
Gluck and Zeller	1881	Incision and anastomosis of trachea (dog)	Good
Kuester	1884	Excision, stricture of trachea and anastomosis (human being)	Successful
Scott	1928	Primary suturing of incised trachea (human being)	Good
Nach and Rothman	1943	Primary suturing of incised trachea (human being)	Good
Maisel and Dingwall	1950	Excision of short segments with anastomosis (dogs)	Stenosis (1 case)
Gebauer	1950	Reinforced dermal grafts for bronchostenosis	Conservation of lung
Daniel	1948	Vitallium, stainless steel mesh, and glass	No long-term successes
Longmire	1948	Lucite prostheses	No follow up
Jarvis	1951	Stainless steel tube	Death from metastases
Rob and Bateman	1949	Stainless steel and tantalum mesh	Satisfactory result
Belsey	1950	Wire coil	Satisfactory result
Bucher	1951	Stainless steel mesh	Satisfactory result
Edgerton	1952	Wire mesh	Satisfactory result
Paulson and Shaw	1955	Plastic operations	Conservation of lung
Abbott	1955	Plastic operations	Conservation of lung
Bikfalvi	1955	Plastic operations	Conservation of lung

TABLE II. EXPERIMENTAL DATA

TYPE OF REPAIR	RESULTS
Preserved tracheal homografts	Liquefaction, necrosis, stenosis
Diced cartilage molds	Liquefaction, necrosis, disruption
Lucite tubes	Angulation, granulation, tissue obstruction
Steel wire coils	Temporary support
Tantalum and stainless steel mesh	Best results at present

of a truly rigid tube. The meshes may be covered with skin or fascia, if necessary, and most important, the mesh structure provides a bridge for the lining of the prostheses with the host tissue.

EXPERIMENTAL DATA

The experiments on tracheal reconstruction were begun at the George Washington University in 1949, and involved the following: tissue grafts, Lucite tubes, hollow bones, steel wire coils, tantalum and stainless steel mesh.*

Tissue Grafts.—The first experiment included the removal of segments of the cervical trachea, six rings in length, in 10 dogs, with replacement of the segments with preserved trachea. The tracheal grafts were preserved in modified

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*Steel mesh obtainable from United Surgical Supplies Company, Mamaroneck, N. Y.

Tyrode's solution with antibiotics and maintained at minus 4° C. No graft was older than 14 days. The fate of the homograft was determined by sacrificing the dogs at certain intervals (Table III).

TABLE III. TRACHEAL HOMOGRAFTS

DOG NUMBER	DAYS SURVIVED	CAUSE OF DEATH
AU-4	1	Tension pneumothorax
AV-11	8	Not much wrong (sacrifice)
AV-6	7	Pneumonia
AW-3	34	Stenosis, pneumonia
AW-1	25	Pneumonia
AW-013	26	Pneumonia
AX-19	1	Distemper
AX-22	3	Distemper
AY-042	1	Killed because of anoxic paralysis
AY-043	1	Never regained consciousness

The homografts, after one week, seemed to be well healed but, in the period of three weeks, there was beginning liquefaction and necrosis (Fig. 1). In one animal, which lived 34 days, there was a stenosis causing death. Our results were similar to the findings of Ferguson and his co-workers and, accordingly, further studies with homografts were abandoned.

In a second group of 9 animals, the use of cylinders of diced cartilage was studied (Table IV). The method of Peer[19] was employed. Four costal cartilages were diced and placed in a mold of heavy, stainless steel mesh with a glass tube in its center. The ensemble was then implanted into the rectus sheath of a dog. Three months later it was removed and the mesh dissected from the cartilage (Fig. 2). After removal of the glass tube, the hollow cartilage was trimmed to the desired length. These cylinders were composed of a mixture of 50 per cent homologous and 50 per cent autogenous cartilage.

TABLE IV

DOG NUMBER	AGE OF GRAFT	SURVIVAL TIME
	Diced Cartilage	
BB-067	—	—
BC-086	—	—
BC-085	126 days	Died, 6 days, empyema
BE-0107	113 days	Died, 14 days, pneumonia
	50% Homologous—50% Autogenous Cartilage	
BT-311	Good mold discarded	—
BT-300	Mold liquefied	—
BU-331	Not transplanted	—
BU-333	150 days	Sacrificed in 120 days for study
BU-334	Incisions opened up in 2 days	

Later, completely autogenous cartilage was tried. These cartilaginous tubes were placed in the cervical trachea after removal of several rings. The experiment was a total failure; although the diced cartilage maintained its integrity in the rectus sheath, it liquefied when transplanted to the trachea. The combinations of homologous and autogenous diced cartilage not only failed in the rectus sheath, but were totally unsatisfactory after being placed in the trachea (Fig. 3).

Lucite Tubes.—Since there has been considerable work with Lucite tubes, only 3 animals were studied with this material. A portion of the cervical

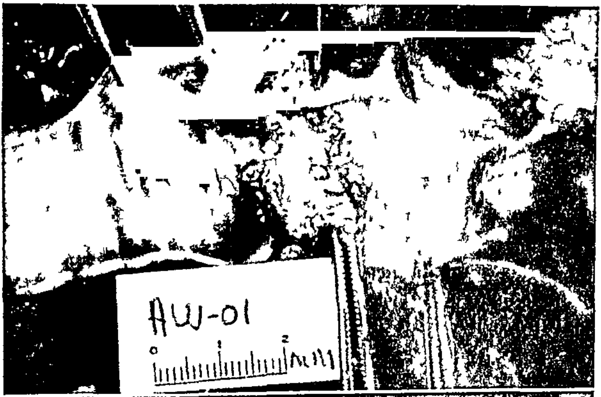

Fig 1

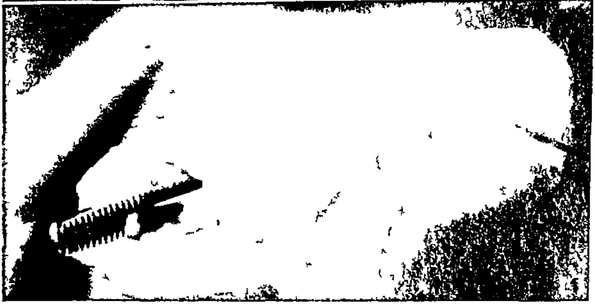

Fig 2

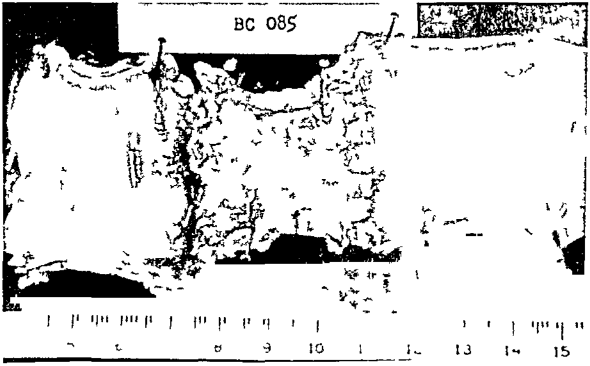

Fig 3

Fig 1 —Tracheal homograft twenty five days after insertion Note beginning liquefaction
Fig —Molded cartilage One hundred and twenty six days
Fig 3 —Cartilage graft six days after insertion in trac

trachea was excised and a Lucite tube of similar diameter was telescoped into the two ends and held in place by sutures around the trachea and tube. These prostheses were satisfactory in maintaining a noncollapsible airway, but the animals died of pneumonia from 3 to 9 weeks following the operation. At post-mortem examination, the prostheses were found in place, held to the trachea with fibrous tissue. In 2 of the 3 animals, a portion of the trachea had telescoped over the tube and undergone necrosis. There was no gross evidence of respiratory epithelium lining the prostheses, but there was a moderate amount of granulation tissue between the ends of the trachea and the tube. Distal tracheobronchial segments were filled with purulent mucoid secretions. These experiences are similar to Daniel's, who demonstrated that solid tubes of Vitallium, glass, and stainless steel were unsatisfactory because the animals died of pneumonia and suffocation. Stenosis does not occur, or is late, because angulation is prevented with the rigid prostheses (Table V).

TABLE V. TRACHEAL RECONSTRUCTION WITH WIRE SPRING (ENTIRE CIRCUMFERENCE)

DOG NUMBER	SURVIVAL TIME IN DAYS	CAUSE OF DEATH
BO-191	5	Pneumonia
BO-184	88	Pneumonia
BR-257	25	Pneumonia
BL-3	11	Empyema, lung abscess
BU-330	22	Pneumonia

Steel Wire Coils.—Coils were wound, from No. 28 stainless steel wire, into various diameters. In 5 dogs, five segments of the cervical trachea were removed and the steel wire coil inserted into the defect (Fig. 4). In 2 cases, the coil was placed in the thoracic trachea and covered with a full thickness skin graft. In the remaining 3 animals, the coils were inserted into the cervical trachea without the skin graft covering. Three animals died between the first and third weeks, 2 of pneumonia and one of empyema and lung abscess. The remaining 2 dogs lived one month and 3 months, respectively. Pneumonia and distemper were the cause of death in both animals (Fig. 5).

At autopsy there was no evidence of respiratory obstruction. There was no excessive granulation tissue about the anastomotic line. The springs were found lying free within a fibrous tube. Microscopic sections showed fibrous scar tissue with inflammatory reaction. Only scattered respiratory epithelial cells could be identified.

Experiences of others and our own observations justify the conclusion that the amount of tissue loss will predict the success of the repair. Experi-

TABLE VI. TRACHEAL RECONSTRUCTION
180 DEGREES POSTERIOR
STAINLESS STEEL MESH

DOG NUMBER	DURATION OF SURVIVAL (DAYS)	FINDINGS
CM-853	90	Sacrificed; clean mucosa
CO-929	82	Sacrificed; clean mucosa
CO-936	1	Detachment of graft, put in too tightly
CN-903	76	Sacrificed; clean mucosa
CO-935	27	Stenosis
CP-954	63	Sacrificed; clean mucosa

ments were then designed to determine the effect of the amount of the circumference of the trachea which had been resected (Table VI).

To study this problem, prostheses were placed in the trachea after 180 degrees of circumference was removed for a distance of five to seven tracheal segments. In one half of the animals, the anterior portion of the organ was excised; in the remaining dogs, the posterior one half was removed. Steel wire coils were employed as prostheses. In animals subjected to resection of the cartilaginous portion of the trachea, the membranous tissue was tacked out laterally to maintain normal tension. The muscles of the neck were sutured around the steel coils. Three of the animals died during the second to the sixth week—one from subcutaneous emphysema, one because the coil was dislodged, and the remainder from pneumonia. In animals that died prior to one month postoperatively, and in animals sacrificed during the same period of time, there was no evidence of respiratory distress. In the dogs which survived 70 to 120 days, or were sacrificed during this time interval, respiratory epithelium could be demonstrated in the cylinder. The points of contact between the steel

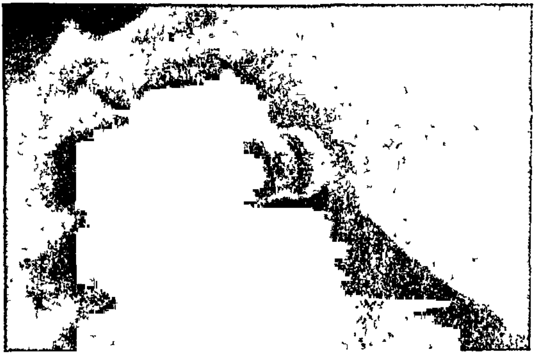

Fig 4

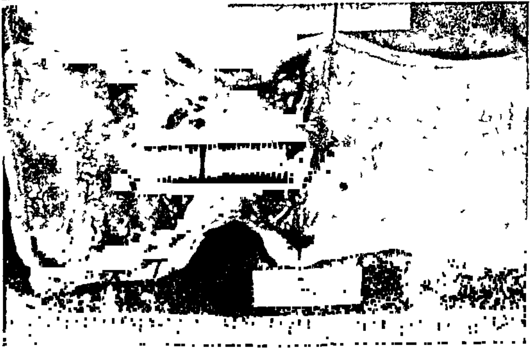

Fig 5.

Fig. 4—Roentgen appearance of wire coil in cervical trachea of dog.
Fig 5.—Appearance of trachea and coil three months after insertion

spring and trachea, however, were devoid of respiratory epithelium. The findings were identical for the series of animals subjected to the repair of the anterior and posterior halves of the trachea.

It became apparent that the steel coil spring was not a satisfactory prosthesis. Accordingly, further observations were made employing tantalum and stainless steel meshes. Koontz's[20] original study of these two metals in connection with inguinal hernia repair is similar to our impression that tantalum causes more tissue reaction than stainless steel. Moreover, steel meshes provide more rigidity with less tissue reaction.

Mesh Prostheses.—Mesh was employed in the following manner: (1) replacement of the anterior, cartilaginous portion of the trachea, (2) replacement of the posterior membranous portion, and (3) replacement of the entire circumference of the trachea. In all instances, six tracheal segments were removed and the mesh placed in the defect.*

Replacement of the Cartilaginous Portion of the Trachea.—Five dogs were subjected to the resection of the anterior portion of the trachea. The longest survival was for 14 weeks. The remainder of the animals were sacrificed after one month. In every instance it was possible to demonstrate that normal respiratory epithelium regenerated over the mesh and lay on the fibrous connective tissue which had grown through the interstices of the mesh. In several cases there was sufficient contraction of the fibrous tissue with constriction of the mesh which could have ultimately caused obstruction. Subsequent clinical experiences have made this observation of considerable importance. The respiratory epithelium within the mesh was pink, glistening, and smooth (Table VII).

TABLE VII. TRACHEAL RECONSTRUCTION
180 DEGREES ANTERIOR
COILED STEEL WIRE, TANTALUM MESH, STAINLESS STEEL MESH

DOG NUMBER	DURATION OF SURVIVAL (DAYS)	FINDINGS
CG-579	19	Coil dislodged; obstructed
CE-553	98	Distemper
CH-583	91	Sacrificed
CG-571	98	Stenosis
CA-494 (Tantalum)	62	Infection
CG-580 (Tantalum)	22	Sacrificed
CT-137 (Steel mesh)	70	Sacrificed
CV-232 (Steel mesh)	43	Sacrificed

The regeneration of respiratory epithelium was equally satisfactory in animals with posterior and anterior resection of the trachea. It is important to emphasize, however, that potential or actual stenosis was much more common when the anterior portion of the trachea was resected. This has an important clinical application (Figs. 6 and 7).

Replacement of the entire circumference of the trachea gave the poorest result. Twelve dogs were used in this experiment; none lived over 52 days. In most cases, death was due to gradual stenosis of the prostheses. It is interesting, however, that in these animals frequent bronchoscopic examinations revealed clean mucosa with no granulation or ulceration These findings indicated that the gauge of the mesh to be employed should be determined by the amount of circumferential damage Small defects are best treated with the finer meshes Larger ones require heavier, more rigid prostheses Subsequent experiences with stainless steel mesh both in the laboratory and in human cases have verified these observations (Tables VII and VIII)

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*Stainless steel mesh in the original animal experiments was supplied by Davis & Geck, Inc.

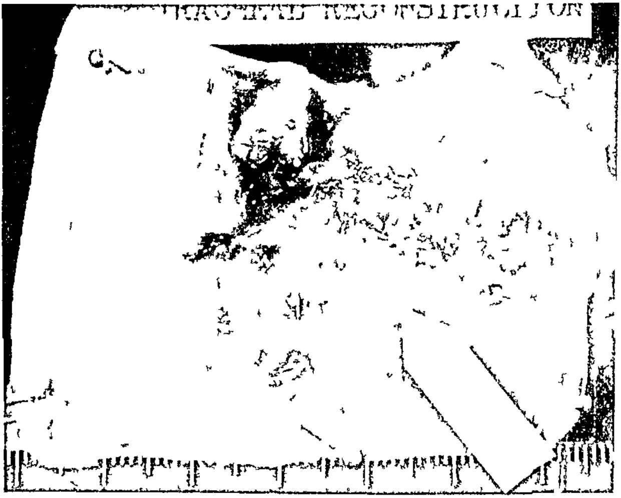

Fig 6—Tantalum mesh prosthesis anterior Note bent mesh and incomplete tissue healing Twenty two days

TABLE VIII TRACHEAL RECONSTRUCTION
360 DEGREES
TANTALUM AND STEEL

DOG NUMBER	DURATION OF SURVIVAL (DAYS)	FINDINGS
CI 600	2	Stenosis due to bending of prosthesis
CG 576	2	Nothing wrong
CJ 612	27	Stenosis due to bending of prosthesis
CJ 617	16	Infection of trachea, wire detached
CL 798	42	Stenosis
CL 802	21	Stenosis
CU 156 (Steel)	1	Blood clot, bronchus
CQ 1 (Steel)	52 (died)	No autopsy
CV 238	8	Stenosis
CV 235	12	No autopsy
CV 230	1	Leaked
DI 831	1	Leaked

Correlation of experimental observations and clinical experiences are recorded in the following case reports It has been established that early primary suture of tracheal defects is the treatment of choice There are, however, cases in which prostheses must be employed to restore continuity of the organ. If it is impossible to reconstruct the trachea or a major bronchus without the aid of a prosthesis, it appears that stainless steel mesh is the most desirable available material.

When reconstruction is being considered, one must assess the lesion in this fashion: (1) Site—cervical or thoracic trachea, anterior or posterior wall of

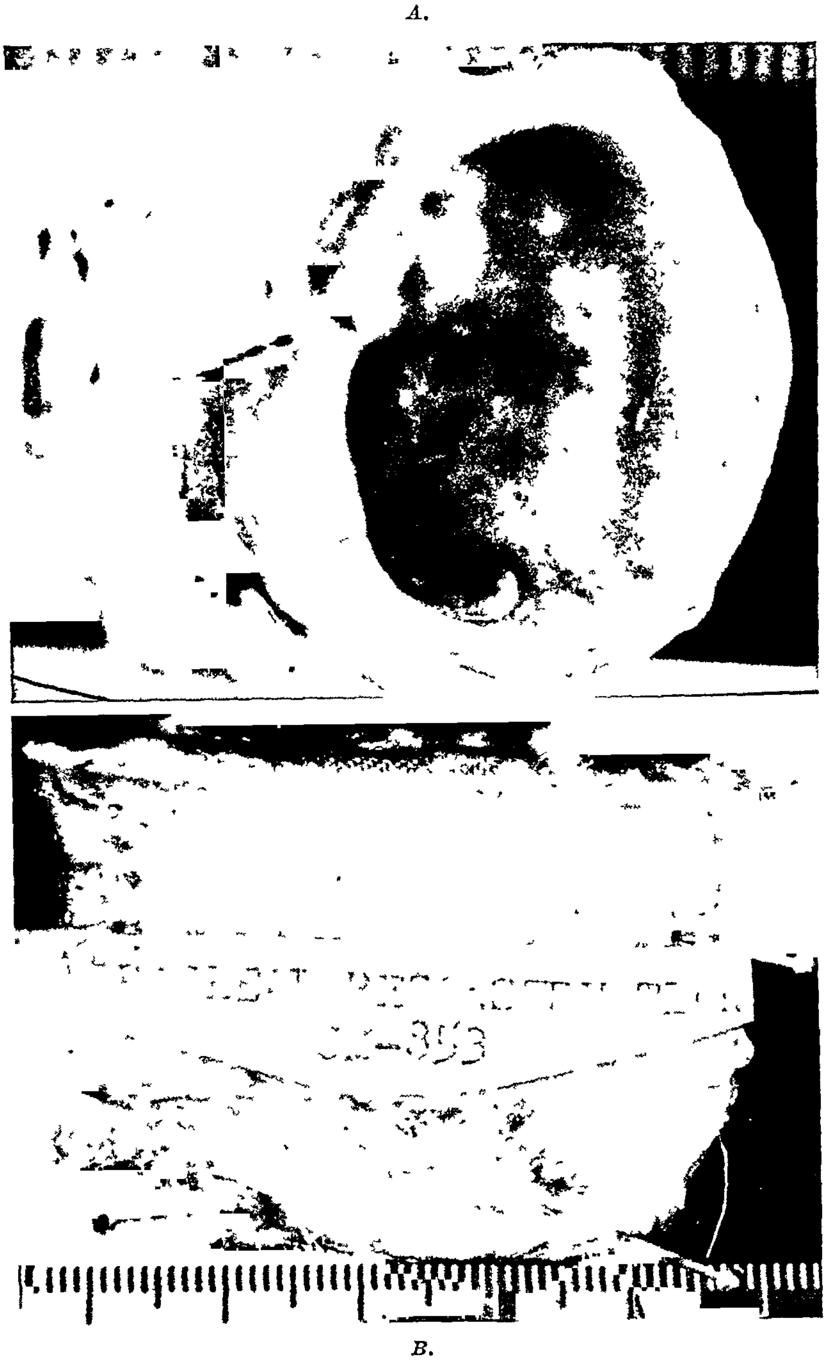

Fig. 7.—*A*, Stainless steel mesh, posterior wall. Eighty-two days. *B*, Specimen opened

the trachea. (2) Extent—either the entire or partial circumference of the trachea involved, and (3) whether loss of substance exists. In this manner, the degree of success of the reconstruction may be predicted

Table IX shows a series of 9 cases, outlining the salient features of each case Representative cases from this series will be more fully described as follows

TABLE IX. TRACHEAL REPAIR

CASE	TYPE OF LESION	SITE	EXTENT OF LESION	TYPE OF REPAIR	RESULT
1	Inflammatory stricture	Thoracic portion	8 cm long; 270 degree circumference	Coiled spring steel	Died postoperatively
2	Self inflicted	Cervical trachea	270 degree loss of substance	Stainless steel mesh	Good
3	Polypoid mass	Thoracic portion	3 cm, 270 degree circumference	Stainless steel mesh, No 48, lined	Died, delayed hemorrhage
4	Automobile accident	Cervical trachea	Complete section of cervical trachea; both recurrent nerves injured	Stainless steel mesh	Failure
5	Automobile accident, laceration with stenosis	Thoracic portion	270 degrees	Incision and transverse repair	Good
6	Automobile accident, laceration with stenosis	Thoracic portion, lower third	180 degrees	Incision and transverse repair	Good
7	Inflammatory stenosis	Right main stem bronchus, middle lobe orifice		Resection, middle lobe, incision and repair of bronchus	Excellent
8	Fracture with stenosis	Cervical trachea	180 degrees, 4 rings	Stainless steel mesh	Excellent
9	Recurrent carcinoma	Right bronchial stump		Excision, stump, stainless steel mesh covered with fascia	Excellent

CASE REPORTS

CASE 1—A 42 year old Negro woman was admitted to the George Washington University Hospital on Jan 24, 1951 She was transferred from another hospital because of severe stridor and dyspnea The obstruction to the trachea was evident A harsh whistle accompanied each inspiration with audible expiratory wheezes Bronchoscopy, bronchography, and laminograms established a stenosis of the trachea from below the vocal cords to just above the carina

The patient was operated upon Jan 29, 1951 (E J. B). A collar incision was made with a vertical extension over the sternum The sternum was split longitudinally. After the trachea was exposed, it was evident that the cartilaginous rings from the level of the cords to the carina were destroyed. A second incision was made in the right third interspace for better exposure An endotracheal tube was passed into the through a short incision above the carina. The stenosed portion of the trachea was resected. This measured 8 cm. in length. The prosthesis of spring steel covered with fascia lata was placed in the defect.

Examination with the bronchoscope immediately after the operation showed a satisfactory lumen. The patient tolerated the operation well, and repeated endotracheal aspirations were performed to keep the airway clear. The patient died two days later. The lumen of the prosthesis was adequate; however, the entire trachea and major bronchi were filled with thick, tenacious secretions. Both lower lobe bronchi showed severe bronchiectasis.

A proximal tracheostomy should have been performed, not only for control of secretions but for reduction of dead air space. This was not possible because the prosthesis started just below the larynx.

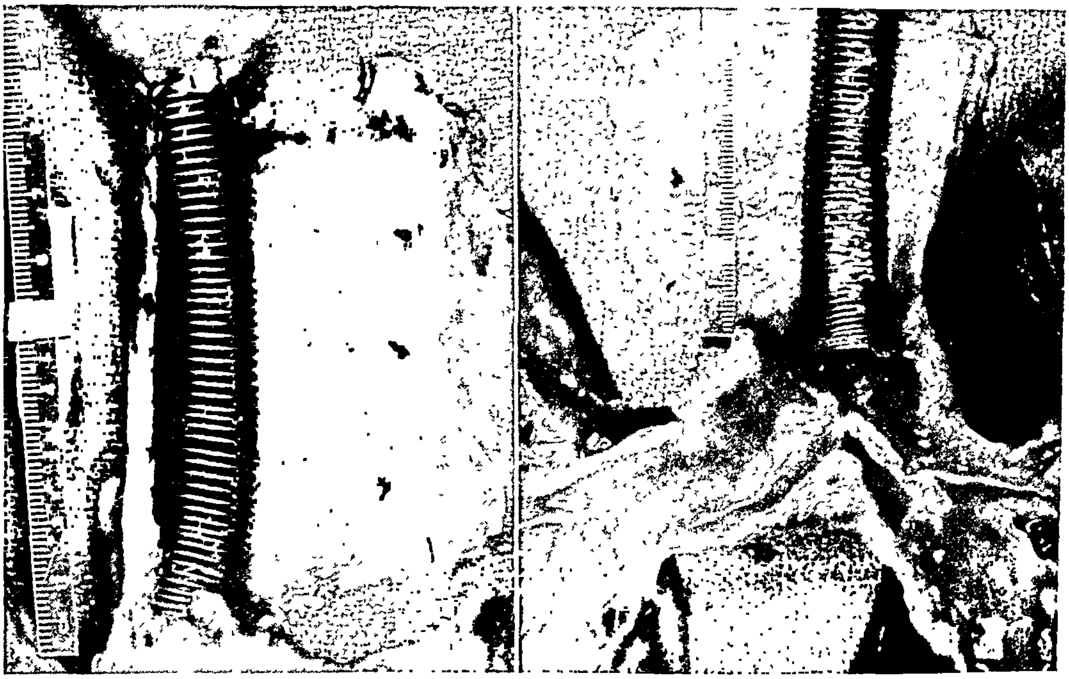
A. *B.*

Fig. 8.—*A*, Case 1, showing coil and fascia lata covering at autopsy. *B*, Case 1. Specimen opened showing thick tenacious secretions.

CASE 3.—A 45-year-old Negro man was admitted to the District of Columbia General Hospital on Oct. 20, 1952, for the third time. All admissions had been the result of chronic respiratory tract infection. In the course of the hospital work-up, a bronchoscopic examination revealed a polypoid lesion in the mid-trachea, which was biopsied and reported to be squamous metaplasia. The patient was treated with antibiotics and bronchodilators. There was no improvement on medical therapy. Persistence of this polypoid lesion, which was increasing in size, was considered an indication for surgical intervention.

On Dec. 2, 1952, the patient was operated upon. A collar incision was made with a vertical component down over the sternum. The trachea was exposed in the neck and by splitting the sternum, additional exposure was gained below. The trachea was mobilized and elevated by using two large tissue drain slings. A small incision was made into the left lateral wall of the trachea. The tumor was seen at the point of incision in the trachea. A segment of trachea, 2 by 3 cm. in size, involving the posterior wall and the left anterolateral wall was excised. The defect was covered with a piece of No. 40 stainless steel mesh. A split-thickness graft was used for the lining of this mesh and the entire ensemble was stitched into place. The new segment was airtight. After the chest had been closed, a proximal tracheostomy was performed in the cervical trachea.

The postoperative course was fairly smooth and the patient was soon up and about the ward (Fig. 9). The tracheostomy tube was removed on the fifteenth postoperative day. The patient complained occasionally of a scratchy sensation in his throat and on occasion coughed up some frothy, blood streaked sputum. On the morning of the twentieth postoperative day, the patient had a fatal hemoptysis.

Autopsy revealed that although the mesh was intact and in place, a small, roughened portion had eroded the wall of the innominate artery.

In subsequent work, a different size mesh has been used and careful attention given to the preparation of the hem to ensure against any rough or protruding edges.

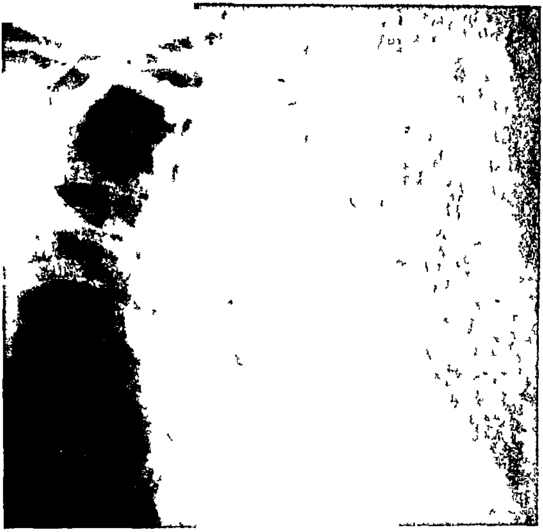

Fig. 9.—Case 3. Mesh in place.

CASE 5.—A 31 year old Army corporal was injured in an automobile accident on Oct. 20, 1952. Among other injuries, he sustained a fractured sternum, with a laceration of the trachea just above the carina. He was admitted to a Station Hospital and a right hemopneumothorax with subcutaneous emphysema was shown on a roentgenogram. The patient's symptoms subsided rapidly and the lung gradually re-expanded. However, on Nov. 2, 1952, the patient again complained of respiratory difficulty. A bronchoscopy performed at that time revealed a laceration of the trachea, involving two thirds of the circumference, from 11 to 7 o'clock, just above the carina. A small flap of mucosa could be seen, which had a to and fro motion on respiration. Tracheostomy was performed which alleviated the respiratory distress. On Nov. 7, 1952, during another bout of respiratory distress, cyanosis and convulsions occurred. The tracheostomy tube was removed and a bronchoscopy was performed through the tracheostomy. The bronchoscopy revealed an area of stenosis at the site of injury, about 2 inches above the carina. Granulation tissue could be seen at this site. It was necessary to improvise a long tracheostomy tube, which was then passed down beyond the site of injury.

The patient was transferred to the Walter Reed Army Hospital, where bronchograms revealed a constriction of the trachea at the previously described site. Since no progress through a short incision above the carina. The stenosed portion of the trachea was resected. This measured 8 cm. in length. The prosthesis of spring steel covered with fascia lata was placed in the defect.

Examination with the bronchoscope immediately after the operation showed a satisfactory lumen. The patient tolerated the operation well, and repeated endotracheal aspirations were performed to keep the airway clear. The patient died two days later. The lumen of the prosthesis was adequate; however, the entire trachea and major bronchi were filled with thick, tenacious secretions. Both lower lobe bronchi showed severe bronchiectasis.

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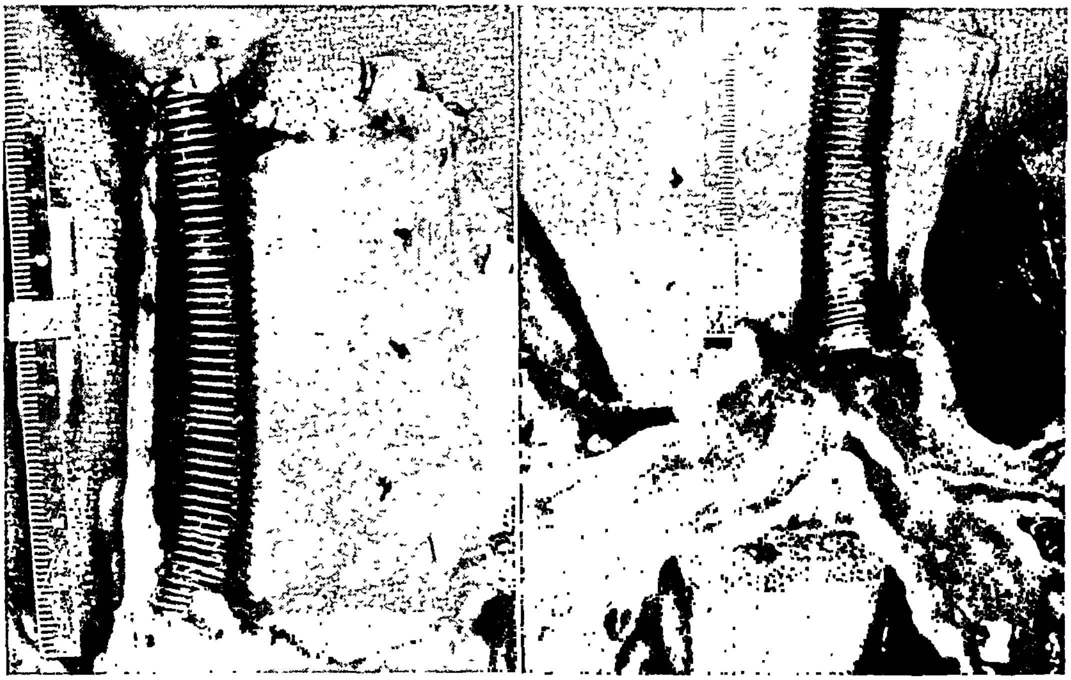
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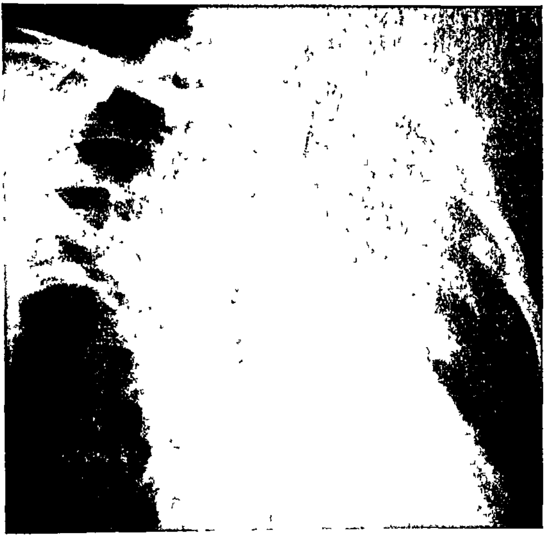

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The patient was transferred to the Walter Reed Army Hospital, where bronchograms revealed a constriction of the trachea at the previously described site. Since no progress in the patient's condition was evident, it was decided to attempt a plastic procedure on the trachea for correction of the stenosis.

On July 9, 1953, through a right thoracotomy, the carina was mobilized. An elliptical piece of trachea, involving the stenotic portion was resected. The defect was then repaired transversely over the indwelling endotracheal tube. The postoperative course was smooth. However, in August, 1953, the patient developed nausea, fever, and loss of weight. In addition, respiratory distress again developed. It was necessary to reinsert the long tracheostomy tube, down past the site of the previous operation. Bronchoscopy revealed that the previous site of repair had again stenosed so that the lumen was markedly decreased (Fig. 10). Through the bronchoscope, with a biopsy forceps, small pieces of the strictured portion were removed, until an adequate lumen was obtained. A tracheostomy tube was reinserted and left in place for a few days. After the tube was removed, the respirations were smooth and the patient was gradually able to resume ward duties without difficulty.

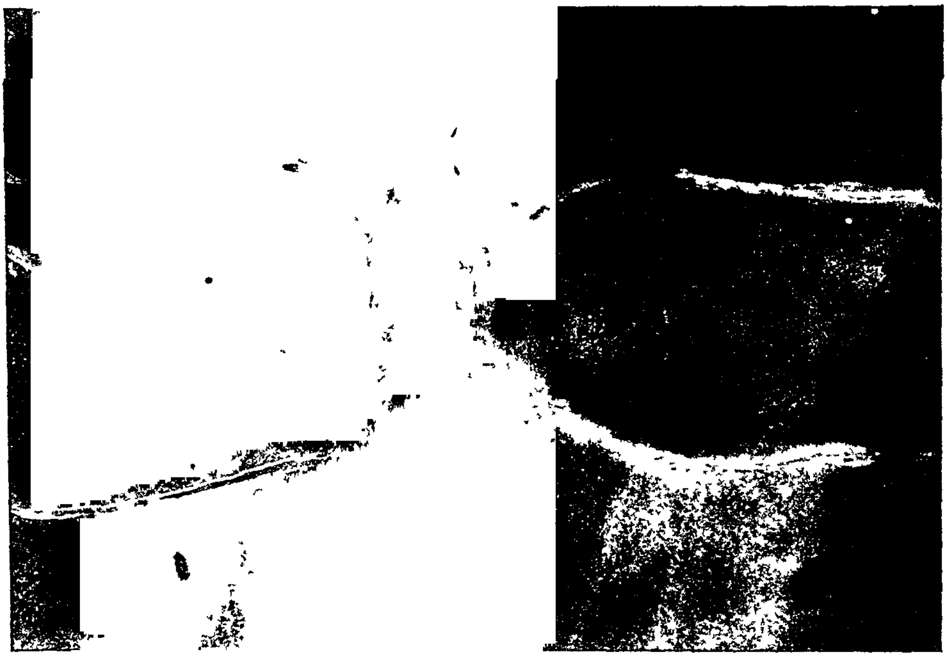

Fig. 10.—Case 5. Lateral view of stenotic trachea. (Retouched by author.)

A bronchogram at the time of discharge from the hospital revealed an adequate lumen. This illustrates how a small difference in the internal circumference of the trachea permits comfortable breathing.

CASE 8.—A 19-year-old Negro male college student was admitted to the George Washington University Hospital for elective repair of a traumatic stenosis of the trachea.

In August, 1955, the patient was involved in an automobile accident, sustaining lacerations of the neck and trachea. An emergency tracheostomy was performed at a nearby hospital. When the patient had recovered from his immediate shock, three separate elective attempts were made to repair the tracheal stenosis. However, in each instance it was necessary to abandon the procedure and reinsert the tracheostomy tube.

Bronchoscopy performed at the George Washington University Hospital was technically difficult because the larynx was distorted from its usual position. Approximately 5 cm. below the vocal cords, the tracheal lumen suddenly narrowed to about 3 mm. in diameter. It was possible to pass a right-angle telescope through the stenosis and the distal trachea was normal in appearance. A tracheogram confirmed this (Fig. 11*A* and *B*).

On Sept. 28, 1955, operation was performed. A flexible endotracheal tube was passed down through the tracheostomy for administration of anesthesia. A long, vertical incision was made from the prominence of the cricoid cartilage to the suprasternal notch. The tissues in the area were difficult to dissect because of dense scar. After the trachea had been exposed, four damaged tracheal rings could be seen. They were crushed and deformed. The anterior half of the trachea, involving the deformed cartilage, was resected and the stenotic area removed. An endotracheal tube was then inserted from above. A previously prepared piece of No. 40, stainless steel mesh was fashioned and rolled to fit the arc and contour of the trachea (Fig. 11C). It was fitted into place over the defect and sutured,

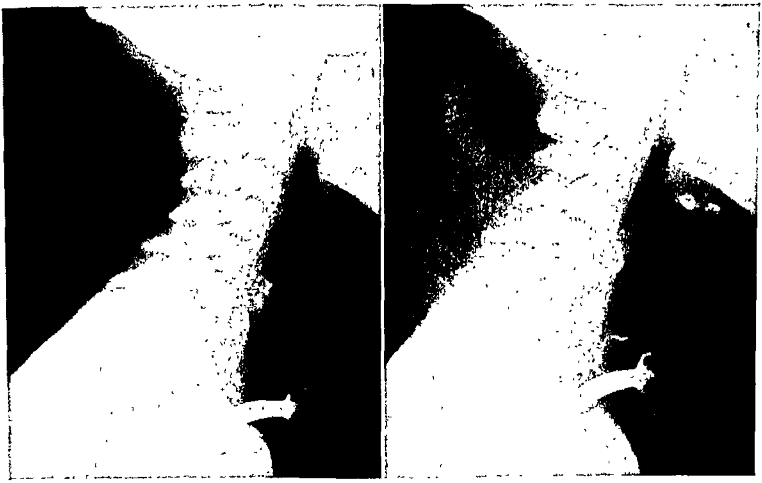
A. B.

Fig. 11, A and B.—Case 8. Lateral views with and without Lipiodol outlining defect.

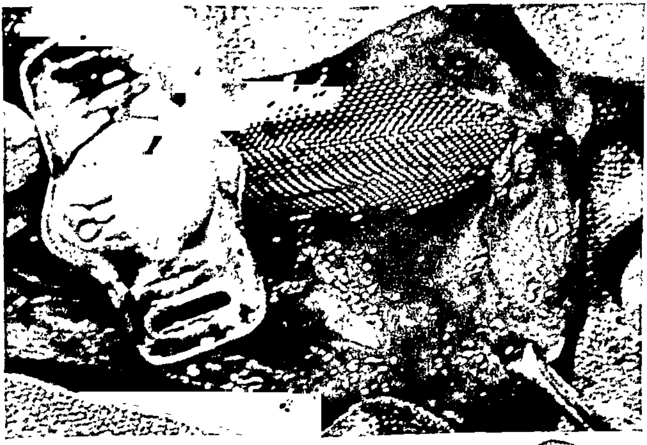
Fig. 11C.—Operation comp[illegible] in place.

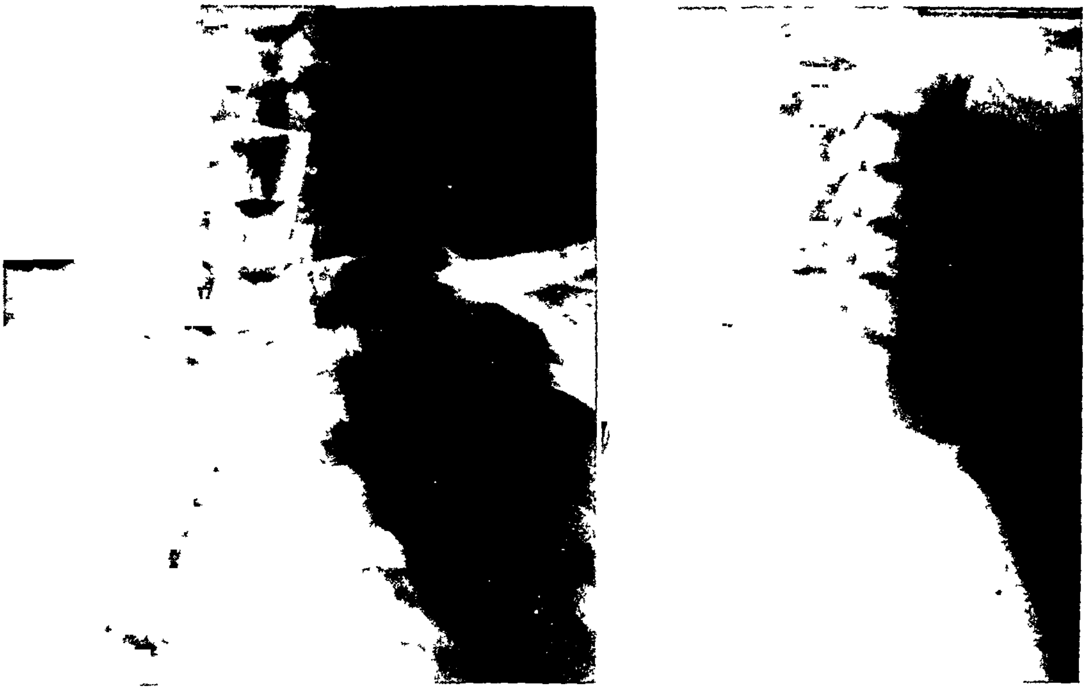

Fig 11*D*—Front and lateral views showing absence of stenotic zone and mesh in satisfactory position

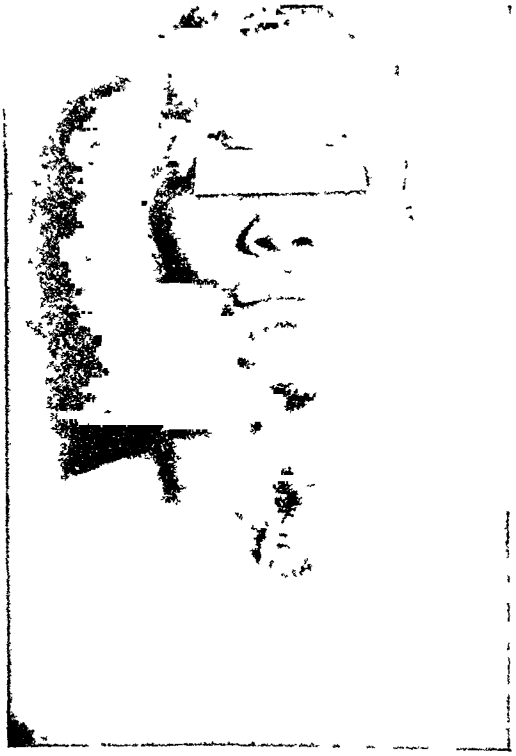

Fig 11*E*—Case 8

using No 32 stainless steel wire A proximal [illegible] was performed through the cricothyroid membrane The immediate postope[illegible] was satisfactory However, the scar developed keloid transformation At [illegible] time insidious respiratory distress and stridor developed It was necessary [illegible] the tracheostomy tube, and subsequent bronchoscopies revealed that the site [illegible] become stenotic Accordingly, a second operation was performed The [illegible]ected and the previously inserted mesh, which had now become twisted a[illegible] removed The edges of

Fig 12—Case 9 Laminogram showing lumen after reconstruction of trachea at right main bronchial orifice

the tracheal defect were freshened A sheath of No 46 stainless steel mesh was prepared, similar to the original prosthesis It was placed over the defect and again sutured into place using No 32 stainless steel wire (Fig 11*D* and *L*)

The postoperative course was satisfactory and the tracheostomy tube was removed in seven days Because of the previous keloid formation, x-ray irradiation was begun The patient's hospital course was entirely satisfactory and he was discharged to return to college He returned for a follow up examination in April, 195[illegible] and there was no evidence of respiratory distress Moreover, no recurrence of the keloid format[illegible] be seen

A successful repair, using the same technique with a stainless steel mesh prosthesis, was performed more than five years ago. The patient has no respiratory difficulty. In this particular case, the second operation was necessary because of compression of the mesh prosthesis by excessive keloid formation.

A combination of heavier mesh and x-ray irradiation to reduce keloid formation was followed by a satisfactory result.

SUMMARY

Experiments were carried out, in dogs, to study the problem of tracheal reconstruction. Tissue grafts, steel wire coil, and tantalum and stainless steel mesh were used. The results were not satisfactory when rigid prostheses were used and when the entire circumference of the trachea was replaced. However, if only the anterior wall or the posterior wall of the trachea was replaced, the incidence of stenosis was decreased. Stainless steel mesh, because of its tissue acceptability, its flexibility and incorporation by the body tissues appears to be a satisfactory prosthetic material.

Nine cases of tracheal reconstruction are presented, in which stainless steel mesh was used as a prosthesis in 5. A steel coil spring prosthesis was used in one, and plastic procedures to restore continuity sufficed in 3. In one case, the use of a stainless steel prosthesis was a failure, in another death occurred after erosion of a great vessel.

Experimental and clinical evidence indicate the superiority of stainless steel mesh for a tracheal prosthesis.

CONCLUSIONS

Whenever possible, suturing of tracheal defects should be performed.

The lesion should be assessed carefully.

If a prosthesis is required, stainless steel mesh is recommended.

Simple plastic procedures are satisfactory for short, stenotic segments.

Proximal tracheotomy is mandatory when a prosthesis is used.

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DISCUSSION

DR DAVID H WATERMAN, Knoxville, Tenn —I rise to report a case of extensive tracheal damage in which the repair failed The patient was a 20 year old girl in whom an automobile accident injury, tracheotomy and subsequent infection resulted in a 360 degree destruction of the trachea for a distance of 7 cm above the carina Several months after the accident, when she was sent to us, a repair was effected by excising essentially the entire stenotic lower trachea and inserting a skin covered and lined stainless steel mesh tube The patient did well for ten days and then died from a torrential hemorrhage from erosion of the innominate artery, which had apparently been considerably weakened when it was dissected out of the mass of scar tissue

Certainly the problem of extensive stenosis, such as this case illustrates, is a very serious one I should like to congratulate the authors both on their presentation and their results

DR OSLER ABBOTT, Emory University Ga —I too wish to compliment the excellence of this presentation There are four small points I wish to dwell upon

First, in a recent attempt by us to remove the entire inner lining of the trachea throughout its length for diffuse papillomatosis we were impressed with the value of a full length sternal splitting incision Temporary transection of the innominate vein and by pass graft for the innominate artery would then allow excellent access to the lower trachea and carina

Second, I wish to present to this Association a follow up of the work presented here two years ago relative to extending the indications for bronchial grafts In the first place, the dermal grafts used in the trachea and bronchi of two children have continued to grow with the children for a period now of five and seven years, respectively In the second place, we reported the use of grafts in patients with carcinoma of the lung There have been 4 patients treated by lobectomy with dermal grafting, and one radical right pneumonectomy with excision of considerable trachea, the carina, and some of the left main stem bronchus All 6 of these patients are still surviving without evidence of recurrence for periods now of 18, 25, 30, 34 and 38 months No delayed stricture or other complication has occurred in this small patient group

Finally, we have been interested in the Papanicolaou studies on the sputum and bronchial secretions of patients with dermal bronchial grafts In one instance, suspicious cells listed as Class III and Class IV have appeared repeatedly for eight months following lobectomy and grafting for a carcinoma in situ

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(Slide) This case illustrates what the authors have described. We used a stainless steel mesh dermograft to replace the tracheal defect, but in addition we feel it is important to emphasize the fact that in reinforcing the graft a pleuroperiosteal flap should be used around the stainless steel mesh. This 38-year-old patient presented herself with the usual symptoms of cough and wheeze. At operation the trachea was isolated, a longitudinal opening was made in the membranous portion of the trachea to identify the extent of the tumor in this area of the trachea.

(slide) The tumor-bearing tracheal mucosal ring was dissected in this manner. Here you see the endotracheal tube.

(slide) The stainless steel mesh dermograft was applied using interrupted fine silk sutures. To help prevent the hazards of this stainless steel mesh from eroding the surrounding vessels, a pedicle flap of periosteum from the chest wall and pleura and surrounding mediastinal tissue was used to encircle the graft. To date, some three or four months following operation, the patient is doing quite well.

DR. K. ALVIN MERENDINO, Seattle, Wash.—We too have had some experience with these methods in human beings. I would like to speak particularly on the experimental approach. A few years ago, Dr. Kirıluk and I were interested in tantalum mesh as a substitute for excised segments of the trachea. This, in our hands, proved unsatisfactory for total circumferential replacement. The problem of replacement in both trachea and esophagus is that of finding a material that is sufficiently firm so that it is not compressible, and yet not so hard that it will erode adjacent tissue.

Recently my associate, Dr. John E. Jesseph, has been working with Ivalon sponge molded to shape, into which he has incorporated fine Lucite rings to simulate tracheal rings. This prosthesis is held in place by a nonsuture method, similar to the multiple-point fixation method that Dr. Hufnagel used for his prosthetic aortic valve. In our opinion, at the present time, this is the best material we have yet utilized in tracheal replacement.

DR. O. T. CLAGETT, Rochester, Minn.—I have enjoyed this paper on tracheal reconstruction very much. One application of tracheal resection and reconstruction that should be discussed further concerns its use in the treatment of tracheal tumors. In a recent study one of my colleagues, Dr. F. H. Ellis, Jr., reported a series of 82 cases of tracheal tumors seen at the Mayo Clinic. These are not common lesions, but they do merit our interest. Some years ago, Dr. J. Grindlay and I carried out some rather extensive studies in the experimental laboratory trying to develop techniques for the resection of tracheal lesions. Using the techniques we had worked out in the laboratory, I have up to the present time operated upon 4 patients with tracheal tumors. In the first, a cylindroma of the lower trachea and right bronchus was removed, and the left main bronchus was connected to the trachea by a polythene tube. This patient died of pneumonia of the left lung approximately one week after operation. In a second case, a polythene tube was used to replace a segment of trachea removed for a primary squamous cell carcinoma of the trachea. This patient died of metastases two years later. In 2 patients, cylindromas of the trachea were removed by local excision and repair of the tracheal defect was made by a wire reinforced fascial graft. One patient died of recurrent tumor over two years later, the other patient was still alive and well when last heard from about four years after operation.

There is a definite need for methods of resection and reconstruction of the trachea for a variety of lesions. Dr. Keshishian, Dr. Blades, and their associates are to be congratulated on the results they have had. I believe that some type of plastic prosthesis, such as Dr. Merendino has described, will provide an excellent means for tracheal reconstruction. Anesthesia and adequate oxygenation of the patient during operation have offered difficulties, in our experience. I am hopeful that with some of the extracorporeal circulation machines that are now being used successfully for cardiac surgery, it will be possible to obviate these problems and that it will be possible to resect and reconstruct the trachea without having to worry about airway and oxygenation problems during the procedure.

DR. BEATTIE (Closing).—We would like to thank the discussants for their contributions to this particular problem, and we want to point out that there are as yet many unsolved problems. Certainly replacement of the entire trachea, although it is technically pos-

1955.[4] To these we now feel obligated to add a size restriction so that our material can be correlated with that of other authors.

1. The nodule must be 6 cm. or less in diameter. Larger nodules have been included only if previous roentgenograms show the lesion to have been smaller than 6 cm. when originally detected.
2. The nodule must be solitary, although small satellite lesions may be present.
3. The nodule must appear to lie within pulmonary parenchyma with aerated lung around it. A relatively minor pleural component has not been considered grounds for exclusion; neither has its proximity to the hilus, provided the lateral roentgenogram shows the nodule to lie anterior or posterior to the hilus. Obvious hilar, mediastinal, diaphragmatic, and chest wall masses have been excluded.
4. Its shape is round or ovoid. Lobulations if present must be minimal.
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Terminology.—There has been considerable diversity of opinion as to what to call these lesions. We originally suggested the term solitary intrapulmonary tumors and many variations of the same idea have been proposed; solitary lung tumors,[5] isolated pulmonary nodules,[6] single, circumscribed, intrathoracic densities,[7] circumscribed discrete pulmonary lesions,[8] circumscribed solitary lung lesions,[9] asymptomatic isolated intrathoracic nodules,[10] solitary circumscribed lesions of the lung,[11] solitary circumscribed intra-thoracic radio-opacities,[12] solitary pulmonary lesion,[13] spherical lesions of the lung,[14] asymptomatic isolated pulmonary nodule,[15] solitary discrete pulmonary densities,[16] circumscribed peripheral shadows of the lung,[17] nodular densities in the lung,[18] etc.

The complete lack of uniformity is confusing and undoubtedly is partly responsible for the way in which the term "coin" lesion[19] has gained such popularity.[20-33] To our mind this is a poor compromise and we have so expressed ourselves previously.[34] As Rigler points out it "is commonly miscalled a 'coin' shadow but actually represents a spherical nodule."[35] Holt and Hodges even go so far as to refer to it as "that odious term 'coin lesion.'"[36] Agreeing in point if not in degree, we prefer to call these lesions solitary pulmonary nodules.

Historical Highlights.—Graham and Singer[37] are generally credited with the first series of resected solitary pulmonary nodules. Their report, published in 1936, concerned three partially calcified benign lesions that were suspected preoperatively of being tumors. No specific etiology was established for any of the three, two being obvious granulomas by present-day standards and the other in all probability a bronchogenic cyst.

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THE SOLITARY PULMONARY NODULE

A Ten-Year Study Based on 215 Cases

Edgar W. Davis, M.D., J. Winthrop Peabody, Jr., M.D., and Sol Katz, M.D.
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In 1946, one of us (E. W. D.), impressed by the general unconcern about the small solitary pulmonary nodule and particularly distressed by the late stages in which so many of these patients were being referred for operation, initiated a study of our own experience with these lesions. In the original group of 40 patients reported in 1947,[1] the malignant proportion was inordinately high and the need for earlier resection was clearly shown. Ten years later, although still short of ideal, the situation is a happier one with patients operated upon sooner, often in the asymptomatic phase, thanks to a wider appreciation of the hazards inherent in the unresected nodule. The radiologist has come to regard it as a diagnostic impasse. An increasing number of practicing physicians, still too few unfortunately, have become aware of the grave responsibility they assume in handling this lesion and are now reluctant to propose a program of observation. Thoracic surgeons are uniformly agreed on the advisability of prompt diagnostic thoracotomy. Even so, we continue to see a regrettably large number of neglected nodules and the problem instead of being resolved has reached tremendous proportions due to the more liberal use of routine and survey chest roentgenograms. It is certainly the most common single indeterminate pulmonary lesion that we see in surgical consultation and at least one radiologist has referred to it as the most urgent problem facing the radiologist today.[2]

Purpose.—To date the main theme of all papers on this subject pertains to the malignant propensities of the group as a whole and the lack of significant radiographic distinctions other than calcification to differentiate the benign from the malignant nodule. One purpose of this paper is to re-emphasize this fairly trite aspect of the problem, but equally important questions remain unanswered, and it is with these issues that this survey is primarily concerned. Chief among these are (1) survival rates of patients with resected bronchogenic carcinoma which presented as a solitary pulmonary nodule; the influence of time factors, symptoms, and mediastinal node involvement upon survivorship; (2) reliability of calcification within the nodule as an indication of benignity; and (3) reappraisal of the etiology of the so-called tuberculoma.

Definition.—Cases have been selected on essentially the same radiographic criteria laid down in 1947[1] and utilized in our subsequent reports in 1950[3] and

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1955[4] To these we now feel obligated to add a size restriction so that our material can be correlated with that of other authors

1 The nodule must be 6 cm or less in diameter Larger nodules have been included only if previous roentgenograms show the lesion to have been smaller than 6 cm when originally detected

2 The nodule must be solitary, although small satellite lesions may be present

3 The nodule must appear to lie within pulmonary parenchyma with aerated lung around it A relatively minor pleural component has not been considered grounds for exclusion, neither has its proximity to the hilus, provided the lateral roentgenogram shows the nodule to lie anterior or posterior to the hilus Obvious hilar, mediastinal, diaphragmatic, and chest wall masses have been excluded

4 Its shape is round or ovoid Lobulations if present must be minimal

5 Its margins are circumscribed and its contour is smooth Extreme sharpness of outline has not been required

6 There is no demonstrable calcium nor cavitation within the nodule

7 There is minimal if any associated pneumonitis, atelectasis, or regional lymphadenopathy Although the majority of these patients have been asymptomatic, an absence of symptoms has not been required for classification under the heading of solitary intrapulmonary nodule

Terminology—*There has been considerable diversity of opinion as to what* to call these lesions We originally suggested the term solitary intrapulmonary tumors and many variations of the same idea have been proposed, solitary lung tumors,[5] isolated pulmonary nodules,[6] single, circumscribed, intrathoracic densities,[7] circumscribed discrete pulmonary lesions[8] circumscribed solitary lung lesions,[9] asymptomatic isolated intrathoracic nodules,[10] solitary circumscribed lesions of the lung,[11] solitary circumscribed intra thoracic radio opacities,[12] solitary pulmonary lesion,[13] spherical lesions of the lung,[14] asymptomatic isolated pulmonary nodule,[15] solitary discrete pulmonary densities,[16] circumscribed peripheral shadows of the lung,[17] nodular densities in the lung,[18] etc

The complete lack of uniformity is confusing and undoubtedly is partly responsible for the way in which the term "coin" lesion[19] has gained such popularity[20-33] To our mind this is a poor compromise and we have so expressed ourselves previously[34] As Rigler points out it "is commonly miscalled a 'coin' shadow but actually represents a spherical nodule"[35] Holt and Hodges even go so far as to refer to it as "that odious term 'coin lesion'"[36] Agreeing in point if not in degree, we prefer to call these lesions solitary pulmonary nodules

Historical Highlights—Graham and Singer[37] are generally credited with the first series of resected solitary pulmonary nodules Their report, published in 1936, concerned three partially calcified benign lesions that were suspected preoperatively of being tumors No specific etiology was established for any of the three, two being obvious granulomas by present day standards and the other in all probability a bronchogenic cyst

TABLE I

ANALYSIS OF REPORTED SERIES

LESION	O'BRIEN, TUTTLE & FERKANEY 1948	EFFLER, BLADES & MARKS 1948	MAHON & FORSEE 1950	SHARP & KINSELLA 1950	HUSFELDT & CARLSEN 1950	ABELES & EHRLICH 1951	EFFLER 1951	HARE & BATTERSBY 1952	BELL & SEALY 1952	WOLPAW 1952	CONDON 1952	STOREY, GRANT & ROTHMANN 1953	HOOD, GOOD, CLAGETT, & McDONALD 1953	DEANS 1953	MAY, ROSE & DUGAN 1954	JONES & CLEVE 1954	MECKSTROTH, ANDREWS & KLASSEN 1954	WU SHAO-CHING et al 1954	WILKINS 1955	HIGGINSON & HINSHAW 1955	AXTMAYER & EHRLICH 1955	COHEN & BORTONE 1955	FORD, KENT, NEVILLE & FISHER 1956	FRENCH et al 1956	DAVIS, PEABODY & KATZ 1956	TOTALS
BRONCHOGENIC CARCINOMA	8	1	2	11	8	5	6	1	8	6	17	4	25	15	8	1	11	1	27	5	2	2	59	4	79	316 } 358 (29.7%)
BRONCHIAL ADENOMA			1	2	1	1		1	3	2			12	2					2	1			5		9	42
PRIMARY SARCOMA	1	1	1			1					1		1				2								2	10
LYMPHOMA		1		1													2								1	5
METASTATIC TUMOR		1	1	3	2	1	1	1	1	2		3	17	1	4		12		6	1	1		1		10	69
TOTAL MALIGNANT	9	4	5	17	11	8	7	3	12	10	18	7	55	18	12	1	27	1	35	7	3	2	65	4	101	442 (36.7%)
GRANULOMA	8	7	48	21	2	5	8	2	10	10	2	30	65	16	18	10	29	8	20	19	6	4	50	22	82	502 (41.6%)
HAMARTOMA	1	1	2	6	5	1	1			2	4	2	25	4	3	2	7		11	9		1	1	3	9	100
BRONCHOGENIC CYST	1	6		8	4				1		1		4	9		1	3		4	2		1	1		6	52
CHRONIC PNEUMONITIS								1					1	4								1	3	7	4	21
ECHINOCOCCUS CYST		1		1										15								1				18
MESOTHELIOMA													3						3						6	12
NEUROFIBROMA		1				1								5					1	1					2	11
CHRONIC ABSCESS	2				1	2							1												2	8
FIBROMA				2						1							3									6
LIPOID GRANULOMA						1													1				1		1	4
HEMANGIOMA		1			1								1				1									4
A-V ANEURYSM										1					1								1			3
THYMOMA						1					1		1													3
LYMPH NODE		1																	1						1	3
LIPOMA														1						1						2
BRONCHIECTATIC CYST						1																1				2
XANTHOMA-MYXOMA												1		1												2
MISCELLANEOUS											1			3	2				1						1	8
TOTAL BENIGN	12	18	50	38	13	12	9	3	11	14	9	33	101	58	24	13	43	8	42	32	6	9	57	32	114	761 (63.3%)
TOTAL CASES	21	22	55	55	24	20	16	6	23	24	27	40	156	76	36	14	70	9	77	39	9	11	122	36	215	1203

In 1942, Alexander[38] emphasized the threat of malignancy in solitary nodular lesions but he obviously had reference to much larger lesions than those we are now considering. The same is true of the report by Thornton, Adams, and Bloch,[39] whose paper, like others appearing later,[40-42] set no restriction as to size or peripheral location of the tumor, hence should not be confused with the very precise lesion we are dealing with in this study.

The evolution of our own interest in this problem has been mentioned in the introduction of this paper. The first published reports of a similar study were those by Effler, Blades, and Marks[5] and by O'Brien, Tuttle, and Ferkaney,[19] both in 1948. Many additional reports have since appeared. Those in which the specific pathologic diagnoses were tabulated plus our own are presented in Table I.[5-15, 19, 23, 28, 29, 32, 33, 43-49] Several papers are not included in this tabulation because of an inadequate breakdown as to the kinds of nodules[21, 50, 51] or because radiologic diagnoses were included.[52]

Analysis of Combined Series.—As Table I indicates, each series has included a significant number of malignant lesions, the military hospitals seeming to have a somewhat lower incidence,[5, 23, 33, 43] due no doubt to the younger age group encountered. Surveying the entire combined series one finds that the malignant lesions make up 36.7 per cent of the total. Taking the bronchogenic carcinomas and bronchial adenomas together, which is amply justified by the malignant potentialities of the adenomas, the percentage of actual and potential primary carcinomas of the lung is almost exactly 30 per cent. Metastatic tumors number 69, over one-half being concentrated in our series and two others.[11, 48] It would appear therefore that the chance of any solitary pulmonary nodule being malignant is almost 40 per cent; the chance of it being a bronchogenic carcinoma, around 30 per cent.

As one would anticipate the largest single pathologic entity in the combined series is the granuloma which comprises 41.6 per cent of all cases. Because of the difficulty in determining which of the tuberculomas were tuberculomas in fact and not just in name, meaning positive identification of the organism, all granulomas have been classified under this broad nonspecific term. Of the assorted benign tumors by far the most common is the hamartoma totalling 100 in all (8.3 per cent) and, in one series,[11] amounting to 16 per cent of the total. A wide variety of other nodules have been reported and will be discussed in detail later. One point requiring explanation is the extraordinarily high number of echinococcal cysts included in the total group. This figure is quite out of proportion to the relative rarity of echinococcosis in this country and merely reflects the inclusion of Deans' report[12] from Australia where the disease is endemic. The total number of cases in these combined series is 1,203, a figure large enough to correct for whatever slight differences may exist between different series in their selection of cases. Thus, the higher rate of malignancy introduced in some series by the inclusion of somewhat larger tumors should be easily offset by the inclusion of calcified and cavitary lesions in other groups.

Analysis of Our Own Series.—Our own experience is based on 215 cases each of which has been carefully selected according to the strict radiologic criteria outlined earlier. These are tabulated in Table II. The material covers a period from 1942 through 1955, with a larger number of cases occurring in each successive year. These figures do not represent the total number of cases seen, for we have always regarded the partially calcified nodule as relatively innocuous and have been content to observe a good number of them. We are firmly convinced that the exclusion of calcified and cavitary lesions from this series is what accounts for the somewhat higher percentage of malignancy in our group. As the Mayo Clinic group has shown, the percentage of malignancy in their series rose from 35 per cent to 42 per cent simply by dropping those nodules with radiographically demonstrable calcification.

TABLE II. 215 SOLITARY PULMONARY NODULES

LESION		CASES	
Bronchogenic carcinoma		79 (36.7%)	
Squamous carcinoma	34		
Adenocarcinoma	27		
Bronchiolar carcinoma	9		
Undifferentiated carcinoma	9		
Bronchial adenoma		9	
Fibrosarcoma		1	
Leiomyosarcoma		1	
Lymphoblastoma		1	
Metastatic tumor		10	
Total malignant		101	(47%)
Granuloma		82 (38.1%)	
Hamartoma		9	
Pleural mesothelioma		6	
Chronic pneumonitis		4	
Bronchogenic cyst		3	
Bronchopulmonary sequestration		3	
Neurofibroma		2	
Chronic lung abscess		2	
Lipoid granuloma		1	
Hyperplastic lymph node		1	
"Aspergilloma"		1	
Total benign		114	(53%)

Of our 215 patients personally operated upon, 101 (47 per cent) had malignant lesions. Ten of these were metastatic but the remaining 91 (42 per cent) were primary pulmonary neoplasms. Nine were bronchial adenomas which, in keeping with their malignant propensities, have been classified with the malignant tumors. The remainder include 79 bronchogenic carcinomas, one fibrosarcoma, one leiomyosarcoma, and one lymphoblastoma.

Of the benign nodules more than two thirds were granulomas (see Table VIII). Wherever possible the tissue blocks from these cases have been resectioned and meticulously studied by Ziehl-Neelsen, periodic acid-Schiff, and Gridley stains. In this way it has been possible to establish a specific etiology in four fifths of the cases. Histoplasma have been demonstrated in over one half of all granulomas so studied. Coccidioides were found in 5 cases and tubercle bacilli in 12. Two of the latter cases actually represented blocked tuberculous cavities and *M. tuberculosis* was easily recovered in culture. Despite exhaustive examination, no organisms could be identified in 12 cases and these have been properly labeled nonspecific. Tissue was no longer available in 15 cases and these are classed simply as granulomas.

There are 17 benign tumors in the series. The most common benign tumor in our group, and this has also been true of combined reported series (see Table II), is the hamartoma. We have excised 9 hamartomas, 2 of them from one patient in operations spaced five years apart. In our experience, pleural mesotheliomas frequently give the impression radiographically of an intrapulmonary location. On six occasions we have operated for solitary pulmonary tumors only to find mesotheliomas. Earlier in our experience these were classified as fibromas. Two intrapulmonary neurofibromas complete the list of benign tumors.

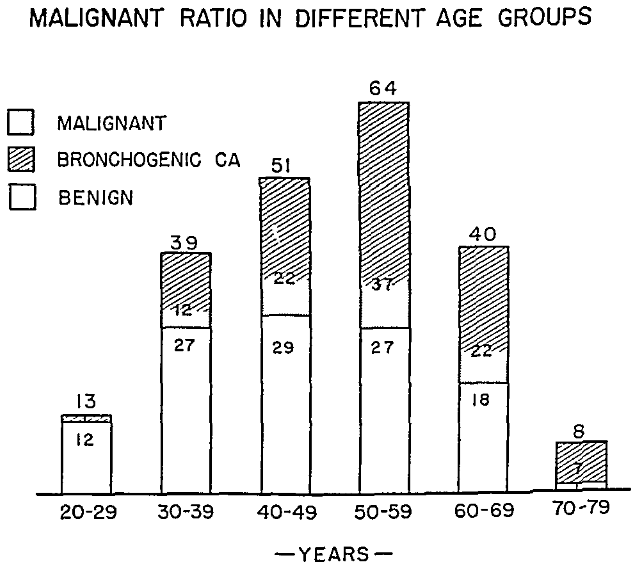
MALIGNANT RATIO IN DIFFERENT AGE GROUPS

Fig 1.—Distribution of 215 solitary pulmonary nodules: malignant versus benign.

Bronchogenic cysts were encountered six times and 3 of these, all located in the right lower lobe, proved to be examples of bronchopulmonary sequestration.

In our figures are included several vague types of inflammation such as chronic pneumonitis, four times, a chronic lung abscess, twice. A careful search was made for an etiologic agent compatible with their indolent character but none could be demonstrated. One patient with lipoid granuloma is included who has been reported elsewhere.[53] The other patients represented unusual conditions, one with a hyperplastic lymph node in the periphery of the lung, another a healed tuberculous cavity filled with a "fungus ball," the so-called "aspergilloma."

TABLE III. AGE AND SEX DISTRIBUTION OF 215 SOLITARY PULMONARY NODULES

LESION	TOTAL CASES	MEN	WOMEN	AGE, YEARS 20 TO 29	30 TO 39	40 TO 49	50 TO 59	60 TO 69	70 TO 79
Bronchogenic carcinoma	79	64	15	--	9	16	30	17	7
Bronchial adenoma	9	5	4	1	1	2	3	2	--
Primary sarcoma	2	2	--	--	--	--	2	--	--
Lymphoblastoma	1	--	1	--	1	--	--	--	--
Metastatic tumor	10	5	5	--	1	4	2	3	--
Total malignant	101	76	25	1	12	22	37	22	7
Granuloma	82	40	42	9	22	19	19	13	0
Hamartoma	9	5	4	1	--	4	3	--	1
Pleural mesothelioma	6	2	4	--	2	2	2	--	--
Chronic pneumonitis	4	4	--	--	--	2	--	2	--
Bronchogenic cyst	3	1	2	--	--	--	2	1	--
Bronchopulmonary sequestration	3	1	2	--	2	--	1	--	--
Neurofibroma	2	2	--	2	--	--	--	--	--
Chronic lung abscess	2	2	--	--	1	--	--	1	--
Lipoid granuloma	1	--	1	--	--	--	--	1	--
Hyperplastic lymph node	1	1	--	--	--	1	--	--	--
"Aspergilloma"	1	1	--	--	--	1	--	--	--
Total benign	114	59	55	12	27	29	27	18	1

The age and sex distribution of our cases are indicated in Table III. The youngest patient was 20 years old; the oldest, 76. As one might predict, the patients with bronchogenic carcinoma were somewhat older than those with other lesions. However, the difference was not as great as in other series. For instance, in two reported series in which solitary nodules were subdivided according to age of the patient,[11, 15] there was a total of 52 patients with bronchogenic carcinoma only one of whom was less than 40 years of age. In our group of 79 patients with bronchogenic carcinomas, 9 were in the 30- to 39-year age group, the youngest being 32. In keeping with reports of the type of bronchogenic carcinoma seen in young people,[54, 55] there was a disproportionately large number of undifferentiated and adenocarcinomas, only 2 of the 9 being squamous carcinomas. In the same age group, our series contains 3 other malignant tumors making a total of 12 malignant tumors as opposed to 27 benign nodules in patients of comparable age. To us this is an extremely important finding, for some have held that the chance of malignancy in solitary nodules in patients less than 40 years of age is practically nil. In our experience the possibility of a nodule being malignant in the 30- to 39-year age group is almost one in three. In the 40- to 49-year age group the chance of malignancy was practically 50 per cent and it was substantially higher in the older groups. Patients with bronchial adenoma had essentially the same age distribution, although 2 of these, ages 27 and 30, represent the youngest patients with malignant tumors in this series.

The distribution of the benign lesions in the various age groups was as expected. The granulomas were fairly evenly distributed with the largest number, 22, occurring in the 30- to 39-year group. Of some significance perhaps is the fact that in the 20- to 29-year group, a very high percentage of patients, 9 out of 13, had granulomas. The oldest patient who had a benign tumor removed (a hamartoma) was a man aged 74. The remainder of the benign nodules were too few in number and too evenly distributed to be of any statistical significance.

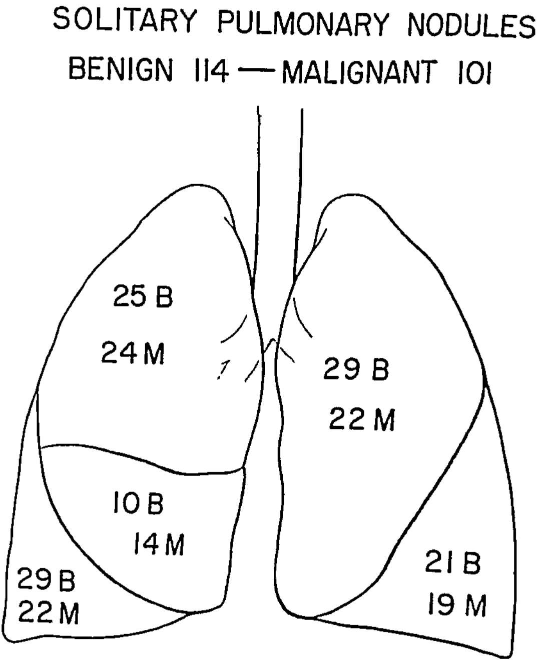

Fig 2.—Graph illustrating the percentage of malignant nodules among differ[illegible] groups. In the older patients the ratio was over 50 per cent but, even in the decade [illegible] years, almost one nodule in three was malignant, a forceful argument against those w[illegible] tend that the chance of malignancy is remote in those under 40 years of age.

The sex distribution was as anticipated. Out of the entire se[illegible] (37.6 per cent) were women. Among the granulomas there was [illegible] even breakdown between women (42) and men (40) and the [illegible] 3 out of the bronchial adenomas (4 out of 9 being women), metastatic [illegible] with [illegible] of 10 being women), and hamartomas (4 out of 9 being wo[illegible]man (1 [illegible]en), and a predominance of females among the patie[illegible] [illegible] those with [illegible] out of 6 being women), bronchogenic cy[illegible] bronchopulmonary sequestration (2 out of [illegible] bronchogenic carcinomas 64 out of 79 (81 per cent) were men. Needless to say, in any given case the patient's sex is of no significance so far as the possibility of malignancy is concerned.

The lobar distribution of the nodules, as shown in Fig. 2, was fairly even with no great difference between the malignant and benign tumors. Since all cases represented circumscribed peripheral lesions, location likewise appeared to have no effect on prognosis.

Symptoms, their presence or absence and their significance, are difficult to evaluate in the patient with a solitary pulmonary nodule. Most of our patients claimed to have no symptoms on initial questioning, yet upon close interrogation a number admitted a slight cough. Percentagewise this was a more common finding in the patient with bronchogenic carcinoma (Table IV).

Table IV. Symptoms Associated With 215 Solitary Pulmonary Nodules

LESION	TOTAL CASES	ASYMPTOMATIC	COUGH	HEMOPTYSIS	CHEST PAIN	ARTHRITIS
Bronchogenic carcinoma	79	42	21	8	5	3
Bronchial adenoma	9	7	--	1	1	--
Primary sarcoma	2	2	--	--	--	--
Lymphoblastoma	1	1	--	--	--	--
Metastatic tumor	10	8	1	--	1	--
Malignant nodules	101	60	22	9	7	3
Granuloma	82	73	9	--	--	--
Hamartoma	9	9	--	--	--	--
Pleural mesothelioma	6	6	--	--	--	--
Chronic pneumonitis	4	1	1	2	--	--
Bronchogenic cyst	3	--	3	--	--	--
Bronchopulmonary sequestration	3	3	--	--	--	--
Neurofibroma	2	2	--	--	--	--
Chronic lung abscess	2	1	1	--	--	--
Lipoid granuloma	1	1	--	--	--	--
Hyperplastic lymph node	1	1	--	--	--	--
"Aspergilloma"	1	--	1	--	--	--
Benign nodules	114	97	15	2	--	--

It should be recognized, however, that 25 patients with bronchogenic carcinoma were observed for periods ranging from one to eight years before being referred to us for surgical consultation. Of these, a certain number had been asymptomatic when the nodule was originally discovered but developed symptoms while under "observation" (Fig. 3, *A* and *B*). Other patients developed symptoms after being told that their x-ray showed a pulmonary lesion. This was particularly true of chest pain which in many instances was of such a vague or fleeting nature that it was not considered worth recording. If on the other hand, the patient complained of clear-cut, persistent chest pain, as did 6 patients in this series, it invariably indicated a malignant lesion. Actually from their subpleural location and rather constant evidence of associated pleural thickening, the granulomas might be expected to cause pain. The Mayo group[11] stated that, out of 65 patients with granulomas in their series, 12 had some degree of chest pain. This has not been true in our experience and we cannot help but suspect that their report must have included instances of mild momentary pains that we tend to disregard.

Among our patients, hemoptysis was another symptom having diagnostic significance. Eleven of our patients had coughed up blood in varying quantities, the sputum usually being only blood streaked. Eight of these patients proved to have bronchogenic carcinoma and another a bronchial adenoma, while among those with benign lesions, there were only 2 patients with hemoptysis, both having a chronic nonspecific type of pneumonitis. One other symptom was most dramatic when it occurred and [illegible] was indicative of a malignant lesion. This was severe arthr[illegible]

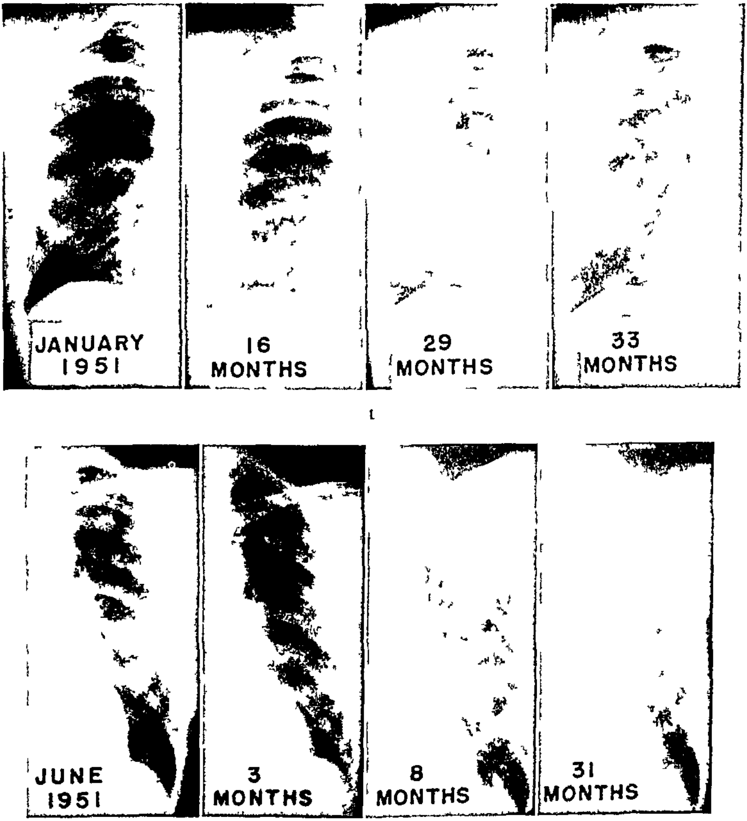

Fig. 3.—Serial roentgenograms of 2 patients with solitary pulmonary nodules neglected for prolonged periods of time. *A*, Despite a delay of almost three years before operation this patient is alive and well more than three years postoperatively even though the extent of tumor required excision of portions of the superior vena cava and trachea. *B*, The second patient represents the more common situation wherein after a comparable delay the tumor is unresectable.

with associated clubbing of the digits. It is well known, of course, that such symptoms not infrequently are associated with bronchogenic carcinoma, and that they are much more commonly associated with peripheral lesions,[56] especially when there is pleural involvement.[57] Three of our patients had severe arthralgia and all 3 had bronchogenic carcinoma. One was invading the pleura, the other two were immediately subpleural in location. None of our pleural mesotheliomas were accompanied by pulmonary osteoarthropathy which is surprising, since this tumor is supposed to have the highest associated incidence of arthralgia and clubbing,[57, 58] although in total frequency, of course, it ranks second to bronchogenic carcinoma. In our experience, the occurrence of arthralgia in association with bronchogenic carcinoma has an unfavorable prognosis, all 3 of our patients with this finding now being dead.

DIAGNOSTIC CONSIDERATIONS

Easily the outstanding characteristic of the solitary pulmonary nodule is the failure to establish its nature by any means other than thoracotomy. We would be remiss, however, if no more than this were said.

History.—The history is rarely of help in establishing a preoperative diagnosis and may actually be quite misleading. Take, for example, the patient who has been known to have tuberculosis and subsequently develops a solitary pulmonary nodule. Although it may be tempting and certainly logical to presume that it is tuberculous, blind adherence to a program of medical management can be disastrous in such a situation. A history of previous cancer surgery may also provide a clue to the etiology of the pulmonary lesion, although on occasion it will prove completely fallacious. This is well demonstrated in our series by 3 patients with a history of having had a malignant tumor elsewhere all of whom proved at operation to have primary bronchogenic carcinomas. As a general rule, however, one is perfectly right in inferring from such a history that the pulmonary nodule is a metastatic lesion. Even so, in any individual case it must constantly be borne in mind that the lesion in the lung may be unrelated to the malignant tumor elsewhere. This is especially true when the period of time between previous surgery and the detection of the pulmonary nodule is relatively long.

Laboratory Examinations.—Routine laboratory studies were of no diagnostic value. Several authors have commented on the significance of an elevated sedimentation rate in these patients, one group feeling that, in the patient with neoplastic disease, the sedimentation rate is elevated often enough to be of serious import[11] while another group was unable to show a very prominent difference in sedimentation rates between those with benign and malignant disease.[32] As far as we are concerned there is no advantage in having sedimentation rates in these patients.

Skin Tests.—Although we have found a perfect correlation so far between the positivity of specific skin tests and the identification of acid-fast bacilli, Histoplasma, and Coccidioides in resected granulomas, we have not found these tests to be of diagnostic significance preoperatively except when all are negative, in which event the chance of malignancy is increased. As a matter of fact, in any patient with a solitary pulmonary nodule, no matter how benign it may appear, the demonstration of negative tuberculin, histoplasmin, and coccidioidin skin tests adds even greater urgency to the need for resection. Preoperatively this is the chief value of skin tests but, in addition, after a grossly granulomatous process has been excised, the skin tests may be of considerable help in limiting the etiological possibilities and suggesting which staining methods are apt to be most productive.

Bacteriologic Examination of Sputum.—Bacteriologic studies of the sputum were of little aid in diagnosis. Of those patients whose lesions ultimately proved to be tuberculous, numbering 12 in all, none were diagnosed preoperatively. Concentrated sputum smears were uniformly negative for acid-fast bacilli in the 8 patients in whom such studies were obtained. Two patients had a positive culture for *M. tuberculosis* returned postoperatively. Considering first, the low yield of sputum cultures in encapsulated tuberculous foci, second, the advisability of surgical resection of most such foci anyway and finally, and most important of all, in view of the urgency of operation for the indistinguishable cases of carcinoma, there is seldom any justification for delaying operation until the reports of sputum cultures return. Also, as pointed out by Waterman,[59] there is considerable hazard in placing extreme faith in a report of acid-fast bacilli in the sputum when the question of malignancy is being considered. For example, 4 of our patients with bronchogenic carcinoma had been observed for periods ranging from one to three years because of a positive sputum smear or culture for acid-fast bacilli. Two of these patients had tuberculosis and carcinoma in combination, but no tuberculous element was discernible in the resected specimens of the other 2 patients nor did either show clinical evidence of tuberculosis postoperatively. These are considered to be false positive reports of acid-fast bacilli, a possibility too little appreciated and too frequently a cause of delay and ultimate inoperability.

Cytologic Examination of Sputum.—The Mayo Clinic report[11] has stressed the value of cytologic examination of the sputum in the preoperative work-up of patients with solitary nodules. In 15 patients with peripheral circumscribed bronchogenic carcinomas, malignant cells could be demonstrated in sputum preparations of 8 (53 per cent). A smaller percentage (23.75 per cent) of a larger series of carcinomas (59 cases) included in the report by Ford and his associates[12] showed cancer cells in the sputum. On the other hand, Wilkins[15] found malignant cells in the sputum of only 3 patients out of 32 with bronchogenic carcinoma who had Papanicolaou studies of their sputum, and one of these turned out to be a false positive report.

Our own feeling, based on an experience similar to Wilkins', is that the value of malignant cell studies is seriously limited by the complete unreliability of a negative report, the occasional unreliability of a positive report and the failure of either a positive or negative report to alter the decision to operate. This last statement might be modified of course in the extremely poor-risk patient in whom operation might be justified only by overwhelming evidence of a malignant lesion. In the management of the solitary pulmonary nodule, we have not been putting private patients to the expense of cytologic studies of the sputum.

Bronchoscopy.—One would hardly expect bronchoscopy to be of diagnostic value in a peripherally situated solitary pulmonary nodule. This proved true in practice and for the past eight years we have seldom seen an indication for bronchoscoping these patients, unless the lesion lies in the vicinity of the hilus.

Roentgenography.—Inasmuch as this lesion is essentially a radiographic one, it is logical that the most elaborate attempts at diagnosis should be along roentgenologic lines. Many points deserve discussion.

a. *Size:* Size somewhat influences the ratio of benign to malignant nodules in that the smaller nodule is more apt to be benign and the larger nodule more apt to be malignant but, in the individual case, size is no guide to the etiology or biologic activity of a nodule. For example, three bronchogenic carcinomas in our series were 1 cm. or less in diameter when originally detected. Twenty-nine others were 3 cm. or less in diameter, while 41 were between 3 and 5 cm. in diameter, another 6 being 6 cm. in diameter. By comparison there were only 4 granulomas that were 5 cm. in diameter. As Fig. 4 illustrates, though, one can be badly deceived if size is used as a guide to management. Regardless of size we feel that any solitary uncalcified pulmonary nodule should be excised.

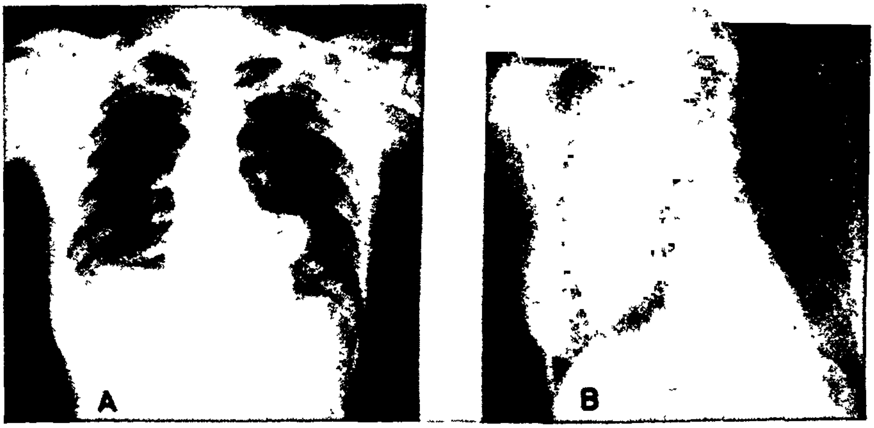

Fig. 4.—Roentgenograms showing the fallibility of size as a guide to diagnosis. The large 5.5 cm. nodule in patient *A* was a histoplasmoma. The small one cm. nodule in the left mid-lung field of patient *B* was an adenocarcinoma.

b. *Sharpness of margin:* Again no rules can be established, for some of the benign nodules in our series have had somewhat hazy borders just as some of the malignant ones have been perfectly smooth, round, and very sharply marginated. In general, however, the benign tumors did tend to have better defined borders, but the difference was slight even on a statistical basis. Most radiologists agree that it is impossible to differentiate benign from malignant nodules on the basis of size or margination and is no better demonstrated than in a comparison of some of the nodules included in our series (Figs. 5 through 9).

c. *Umbilication of margin ("notch sign"):* Attention has recently been directed to the value of an indentation or umbilication of the border of a solitary nodule as a sign of malignancy, the so-called "notch sign" of Rigler.[35, 60]

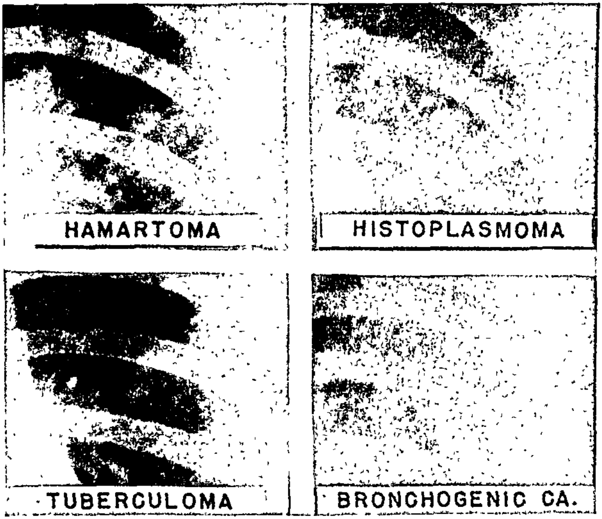

Fig. 5.

Figs. 5-9.—Comparative x-rays of nodules of similar size and location but different etiology. Obviously, to attempt a clinical differentiation between the benign and malignant nodules is virtually impossible.

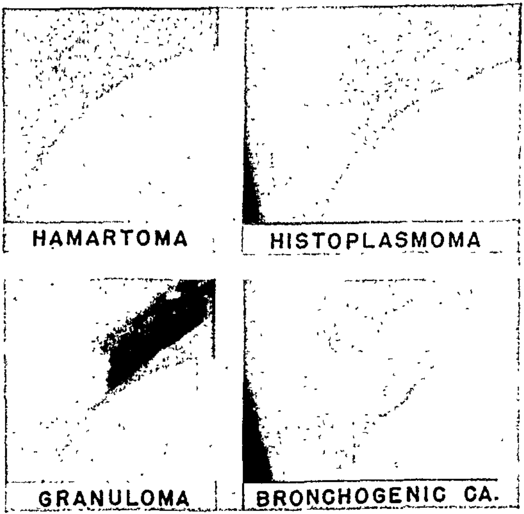

Fig. 6.

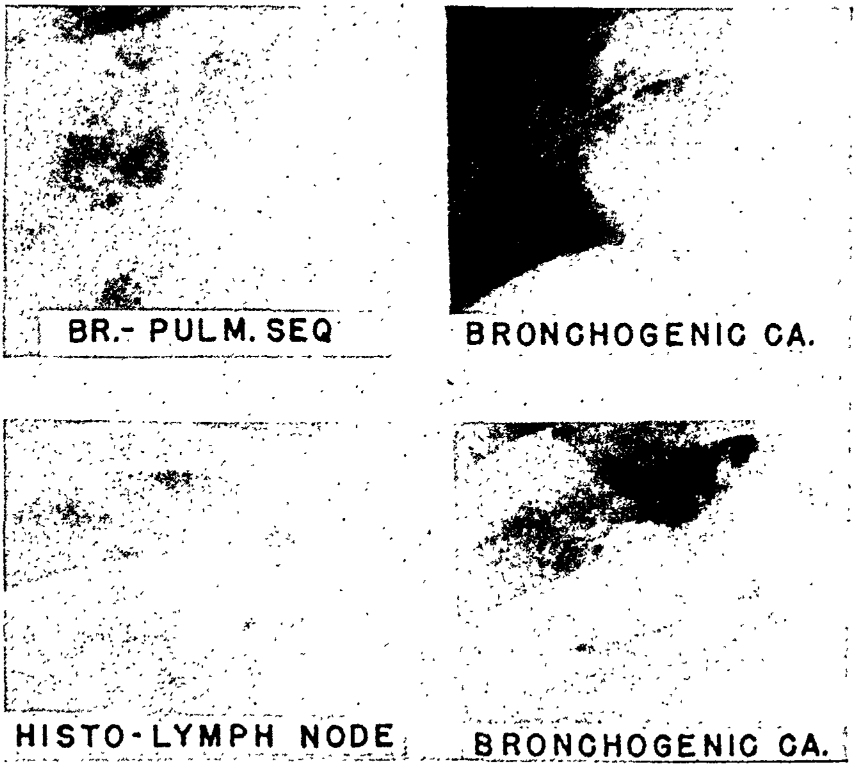
BR.- PULM. SEQ
BRONCHOGENIC CA.
HISTO-LYMPH NODE
BRONCHOGENIC CA.

Fig. 7.

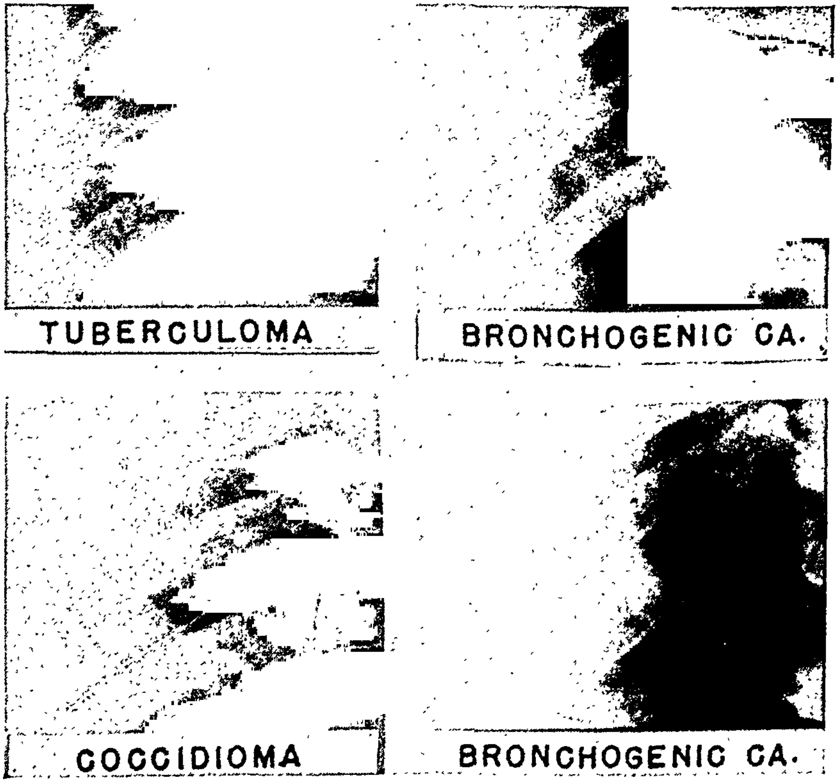
TUBERCULOMA
BRONCHOGENIC CA.
COCCIDIOMA
BRONCHOGENIC CA.

Fig. 8.

It has been impossible to analyze this radiographic feature in our entire series, although we have seen at least 4 cases, all of them malignant, in which a "notch sign" was clearly seen. Less distinctive notches were seen in two granulomas. Rather than argue the reliability of this sign we prefer to question its value as a guide to therapy, inasmuch as the cases in which it is positive usually rate excision anyhow. A truly practical roentgenologic aid would be one that might spare the patient unnecessary surgery.

d. *Recent origin:* One feature strongly suggesting malignancy is the demonstration of recent origin of the nodule. This is contingent of course upon recent x-rays being available showing the appearance of the nodule within a matter of months. This is rarely possible but does constitute good evidence of malignancy when found.

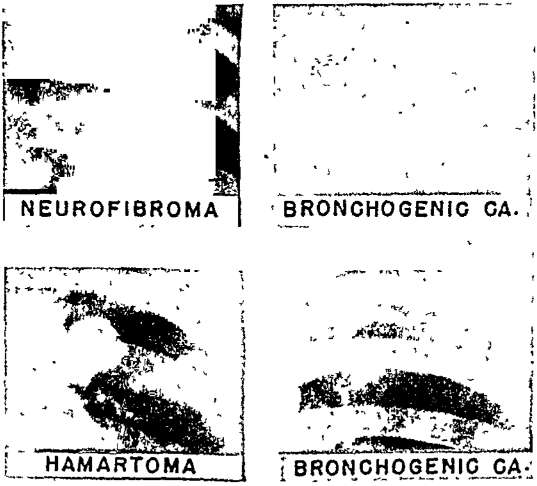

Fig. 9.

e. *Growth:* An enlarging pulmonary nodule is more apt to be malignant and even more so if the enlargement is rapid. Fig. 10 indicates the variability of this sign, however, as shown by rapid enlargement of a coccidioma within the space of two months as compared with no greater enlargement of an adenocarcinoma of the lung transpiring over a two-year span. It is really amazing how imperceptible may be the growth of carcinomas over a prolonged period. One of our patients with an undifferentiated bronchogenic carcinoma presented a nodule that did not appear to enlarge during eight years of preoperative observation, then began to show radiographic evidence of concentric enlargement. There was no evidence in the specimen of an underlying adenoma nor any pre-existing inflammatory process, nothing but undifferentiated carcinoma.

Obviously then, one can be deluded by an apparently stable lesion and we would prefer to have x-rays showing no change going back at least five years before we would agree that observation should continue. The real indictment of a program of "watchful waiting," therefore, rests not alone on the fact that carcinomas may become inoperable in the time between examinations, but more basically than that, upon the erroneous inference that growth necessarily means a malignant lesion or that a lack of growth is any assurance against malignancy.

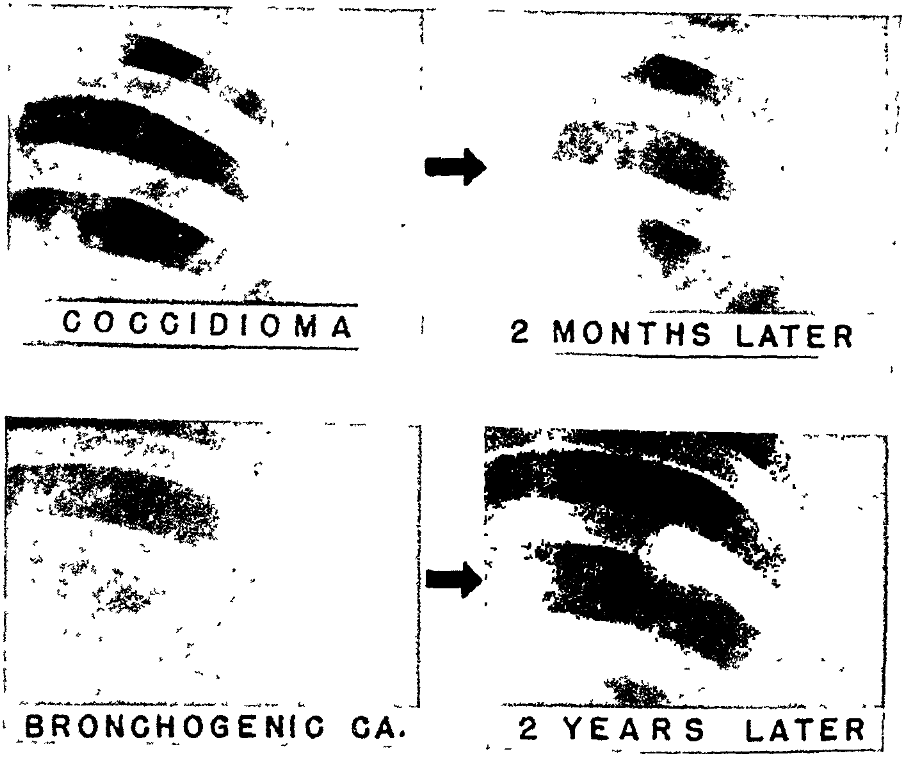

Fig. 10.—Serial roentgenograms showing the unreliability of growth as an indication of malignancy. Both lesions shown were about one centimeter in diameter when initially detected. The coccidioma grew three times its original size within a 2-month period, whereas the carcinoma took more than two years to enlarge to the same degree.

f. *Density:* After carefully analyzing our cases we feel that certain generalizations, none of them absolute, can be drawn from the density of a pulmonary nodule. Those under 2 cm. and dense are usually granulomas while those of similar size but not dense can be either granulomas or carcinomas. Those over 2 cm. and dense can be either granulomas or carcinomas while those of similar size but not dense are probably carcinomas. This point has been stated slightly differently by others,[61] namely, all lesions of medium or small size (less than 3 cm.) of light density should be considered malignant; small lesions of heavy density are less likely to be malignant; as the medium-sized lesions of heavy density approach 3 cm. in size, suspicion of malignancy should rise accordingly. Although such information is helpful in analyzing individual cases, it is hardly reliable enough to dictate policy in the management of these nodules.

g. *Calcification:* We have long contended, as have others,[21, 22, 62-65] that the solitary pulmonary nodule containing radiographic evidence of calcification is so consistently benign that it need not be excised unless serial x-rays show signs of instability. Obviously, for it to serve as a guide the presence of calcium must be unequivocal, it must not be just one of many calcific deposits and it must be shown to lie within and not adjacent to nor superimposed upon the nodule. We have occasionally heard the complaint that the preoperative impression of calcification does not always correlate with pathologic examination of the specimen. In our experience the correlation has been completely reliable, an indication perhaps of our strict requirement so far as the presence of calcium is concerned. If there is any question as to the presence of calcium, we have considered the lesion to be noncalcified and treated it accordingly. At the same time we are in complete agreement with Bloch[66] who found in a beautifully conducted study that the absence of radiographically visualized calcium, in fact the lack of a pronounced degree of radiographic density, does not exclude the presence of fairly abundant calcification. This is well seen in Fig. 11 wherein a histoplasmoma and hamartoma, neither of which showed calcification in tomograms, were shown to contain considerable calcium in x-rays of the specimen. Even then there are those who take vigorous exception to its validity as a sign of benignity.[6, 23, 26, 28, 67] Be that as it may, in a fairly extensive experience with completely and partially calcified pulmonary nodules, we have routinely advised medical observation and have never had cause to regret it. Of innumerable nodules so followed, 3 subsequently displayed concentric enlargement and were then excised, one proving to be a tuberculoma, one a histoplasmoma (Fig. 12), and one a nonspecific granuloma. None of the others have shown signs of reactivation or malignancy (Table V).

TABLE V. *PARTIALLY CALCIFIED PULMONARY NODULES*
SURGICALLY EXCISED BY US

TYPE OF CALCIFICATION	REASON FOR RESECTION	PATHOLOGIC DIAGNOSIS
1. Concentric laminations	Physician's insistence	Nonspecific granuloma
2. Central core	Concentric enlargement	Nonspecific granuloma
3. Inner ring	Patient's insistence	Histoplasmoma
4. Large central core	Patient's insistence	Histoplasmoma
5. Inner ring	Concentric enlargement	Histoplasmoma
6. Central core	Physician's insistence	Histoplasmoma
7. Central core	Patient's insistence	Histoplasmoma
8. Central core	Patient's insistence	Histoplasmoma
9. Diffuse conglomerate	Concentric enlargement	Tuberculoma
10. Central core	Physician's insistence	Granuloma
11. Eccentric flecks	Question of carcinoma	Hamartoma
12. Eccentric flecks	Question of carcinoma	Bronchogenic carcinoma (squamous)

Recently, however, we were disturbed to have a small right apical nodule in which x-rays showed several calcific flecks turn out to be a primary squamous carcinoma of the lung[63] (Fig. 13). A review of the literature indicates that this is an extremely rare occurrence. In 1953, Good,[64] in a wide radiologic experience at the Mayo Clinic, claimed never to have seen a malignant solitary pulmonary nodule containing radiographically demonstrable calcium. In the discussion following his paper, however, Hodes made reference to 4 patients with partially calcified nodules that were ultimately found to be malignant and Riemenschneider cited a solitary nodule showing roentgenographic evidence of calcification which pro a granuloma with a nodule of bronchial carcinoma in its wall. Prior to this the only similar case of which we are aware was one alluded to by Tuttle,[67] but since then several other instances have been reported.[13, 23,* 69,* 70] Moreover, Liebow has demonstrated microscopic calcification in still another.[71] In order to assess the true incidence of this occurrence we thought it advisable to poll the members of The American Association for Thoracic Surgery for, as far as we are concerned, resolution of this question is one of the most important problems confronting thoracic surgeons.

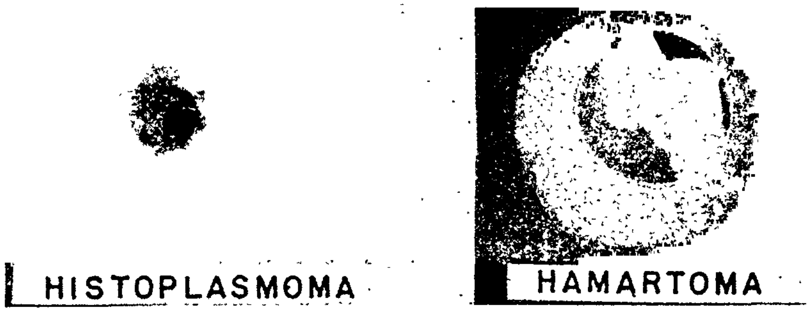

Fig. 11.—X-rays of two resected specimens showing both to contain relatively large amounts of calcium which in preoperative tomograms escaped detection. Repeated examples such as these emphasize that tomograms, because they tend to underestimate rather than exaggerate the amount of calcification, are ordinarily quite reliable when positive.

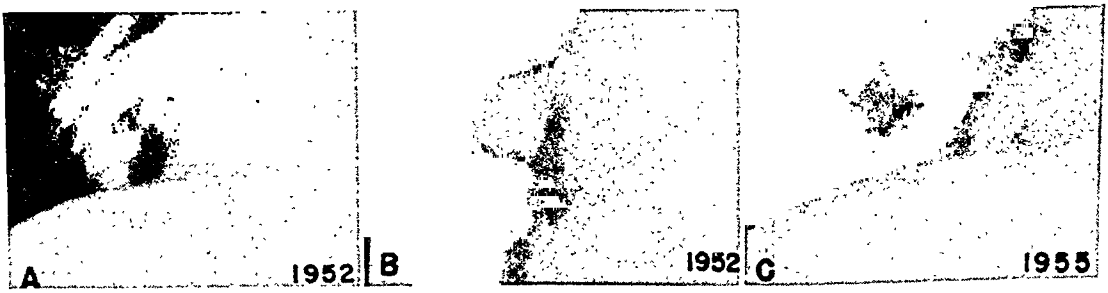

Fig. 12.—The solitary nodule shown in *A* was first picked up in 1952 in a routine chest x-ray. Tomogram (*B*) demonstrated a ring of calcium within the nodule. Histoplasmin skin test was positive. The patient was followed by serial roentgenograms until 1955 when the nodule increased in size (*C*) and was therefore resected. The PAS stain proved it to be a histoplasmoma.

Questionnaires were sent to 452 members of the Association, 9 of whom had died or could not be found. Of the remaining 443, answers were received from 328 (74 per cent).

Question No. 1. In handling the partially calcified solitary pulmonary nodule my usual policy is: Resection ☐ Observation ☐.

Answers:	Resection	143
	Observation	146
	Individualize	7
	Undecided	32
	Total	328

Comment: Opinion evenly divided between observation and resection.

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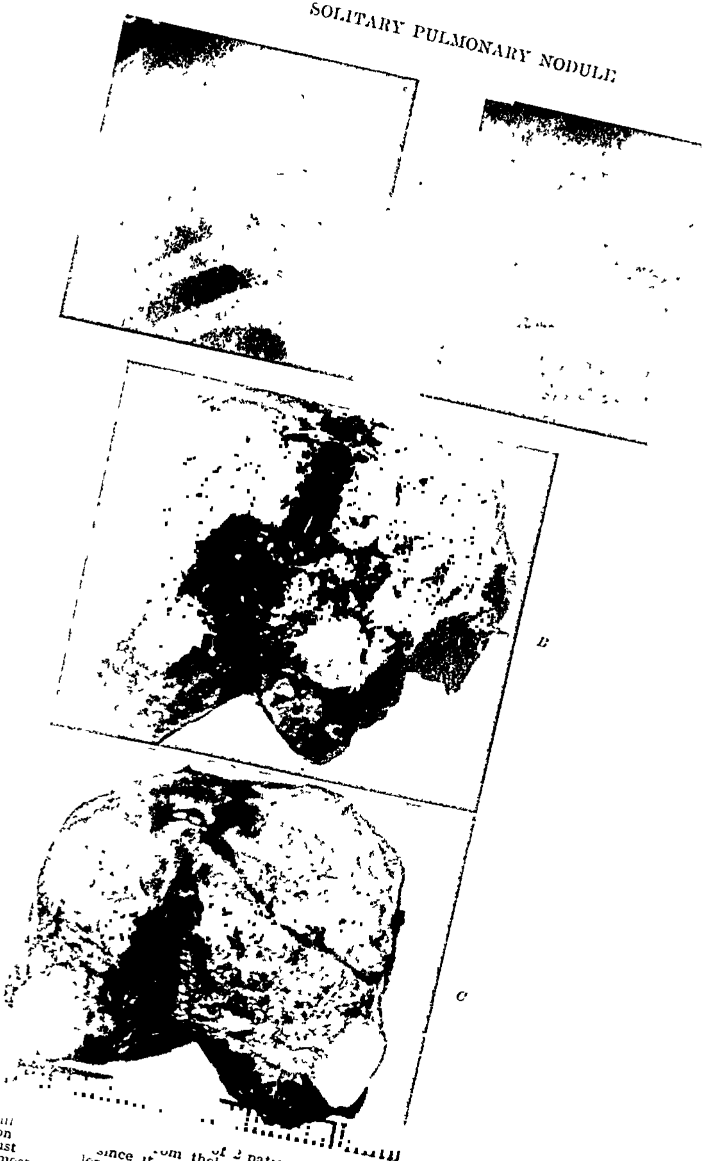
*References 23 and 69 relate to the same case.



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of 2 patients with lesions of contrasting etiology
om their apical location both resemble tuberculomas,
since it contains several calcific flecks. Although the nodule
lomerate tubercles from which acid-fast bacilli were recovered,
ical in its gross appearance, proved to be a squamous car-
nimal calcification is not a justifiable basis for observing a

QUESTION No. 2. Do a few flecks of calcium within the nodule provide adequate assurance of benignity?

Answers:		
	Yes	46
	No	250
	Undecided	32
	Total	328

Comment: Opinion overwhelmingly against the reliability of a few flecks of calcium as an indication of benignity. Same 32 members still undecided.

QUESTION No. 3. Have you ever encountered in your personal experience a malignant solitary pulmonary nodule containing calcium? Yes ☐ No ☐. If so, how many?

Answers:		
	Yes	114
	No	203
	Don't know	11
	Total	328

How many? Answers varied from "one" (by far the majority) to "twelve" (William Weisel) to "too many" (Edward O'Brien).

QUESTION No. 4. If your answer to Question 3 is affirmative, briefly elaborate on the size of the tumor, cell type, and the amount and distribution of the calcium.

Comment: Of the 114 members who had encountered a malignant solitary pulmonary nodule containing calcium, 76 provided a brief detailed report of 155 cases. One was described as 6 cm. in diameter, one as 5 cm. and the rest, one to 4 cm. Breakdown by cell type is enumerated in Table VI.

TABLE VI. ANSWER TO QUESTIONNAIRE
MALIGNANT SOLITARY NODULES CONTAINING CALCIUM
155 CASES—76 SURGEONS

CELL TYPE	NUMBER
Squamous	69
Adenocarcinoma	28
Undifferentiated	10
Metastatic	6
Adenoma	6
Bronchiolar	2
Oat-cell	2
Sarcoma	2
Malignant hamartoma	2
Hemangiopericytoma	1
Not stated	27
	155

The frequency with which partially calcified malignant nodules were reported was quite surprising to us. In analyzing these cases, however, it soon became apparent that the majority were minimally calcified, most containing one or several "flecks" which when described in detail were generally "small" or "tiny." In but one instance were the flecks of calcium described as "large" (Tyson). Most such flecks were eccentrically situated often being referred to as "marginal" or "peripheral." In only 13 cases was the calcific deposit described as centrally situated and in none of these was the calcification large enough to be called a central core. There were, on the other hand, a few instances in which more extensive calcification was reported. These included a 2 cm. adenocarcinoma with "moderate central calcification" (Daughtry), a baseball-sized squamous carcinoma with "marked calcification irregularly dispersed throughout" (Mangiardi), a 5 cm. adenocarcinoma with "extensive calcification" (Harkin), and a 4 cm. "completely calcified" bronchial adenoma (Rosemond). Of Weisel's 12 cases, 10 of which were squamous and 2 adenocarcinomas, the calcification varied from "scanty to plentiful" and somewhat the same was true of Thompson's 4 cases in which the amount of calcium varied from "heavy to light." In none of the cases described was the calcium deposited in the form of a ring or concentric laminations, although one such lesion, a 6 by 5 by 4 cm. adenocarcinoma, was said to have a "calcified capsule" (Hausman). Scattered flecks were mentioned several times but none of these malignant nodules were said to present a diffusely stippled-type calcification.

Of considerable interest was the answer of Dr. C. Allen Good of the Mayo Clinic who, as mentioned earlier, has long been a strong proponent of conservatism in the handling of the partially calcified solitary pulmonary nodule. Like ourselves he has recently encountered a peripheral bronchogenic carcinoma presenting an eccentrically situated nidus of calcium, a case recently reported.[72] Even more significant perhaps was his report of a study carried out by O'Keefe of their clinic who analyzed roentgenologically the specimens of some 200 resected solitary nodules. After enucleating each nodule from the surrounding lung substance, he was able to show evidence of calcification in 10 per cent of the bronchial carcinomas. In some instances it occurred in areas of necrosis, while in others it seemed to represent postinflammatory fibrocalcific deposits that had been engulfed by tumor. Good concluded:

> "While I still believe, as I have stated in several articles, that calcification is usually a sign that the lesion is not malignant, I must admit that I must qualify this belief in the light of the facts available to me. I still believe that we can regard as benign the lesion which is calcified in a laminated fashion or which looks like a 'target.' I also believe that any mass which shows evidence of a large amount of calcium is undoubtedly benign. On the other hand, I think we must be more careful of the lesion which shows a very small central or eccentric nidus or which is only very slightly calcified."

As a result of this survey we too are convinced that the presence of minimal calcification within a solitary pulmonary nodule, especially when it is no more than a small fleck, is unjustifiable grounds for assuming it to be benign. These we now resect unless there are old films available, preferably four to five years earlier, showing the lesion to be unchanged in size and configuration. On the other hand, when dealing with lesions containing a moderate amount of calcium, it would seem fair to be much more conservative. Those that contain a relatively large central core of calcium, those that present concentric laminations, an inner ring or an outer rim of calcium and those that are diffusely stippled or completely calcified are almost assuredly granulomas and can be left alone (Fig. 14). Even then, any increase in size of the lesion should be a cause for alarm regardless of the presence or amount of calcium.

h. *Cavitation:* Lesions that were cavitary when initially detected have been purposefully excluded from this study, first, because the many terms applied to these small radiographic densities, such as, nodule, coin lesion, etc., all imply that the lesion looks solid; second, because their inclusion, like the inclusion of calcified nodules, would weight the statistics in favor of the benign nodule; and finally because the indication for surgery is probably more universally accepted in the case of the cavitary lesion. On the other hand, several nodules are included that were initially solid but showed signs of central necrosis while under observation. Two of these were tuberculomas that excavated but were easily treated by resection plus long-term antituberculous chemotherapy. One was an Aspergillus-packed lung cyst ("aspergilloma" or fungus ball) that ultimately disclosed a meniscus sign. Three others were malignant. One of these was metastatic from the kidney; the other two were bronchogenic carcinomas. The catastrophic result of prolonged observation of one of these is shown in Fig. 2. Equally reprehensible was the other case in which a therapeutic pneumothorax was induced after cavitation occurred and was maintained for over a year while the thick-walled cavity gradually grew larger. Such examples serve to illustrate the great hazard in utilizing

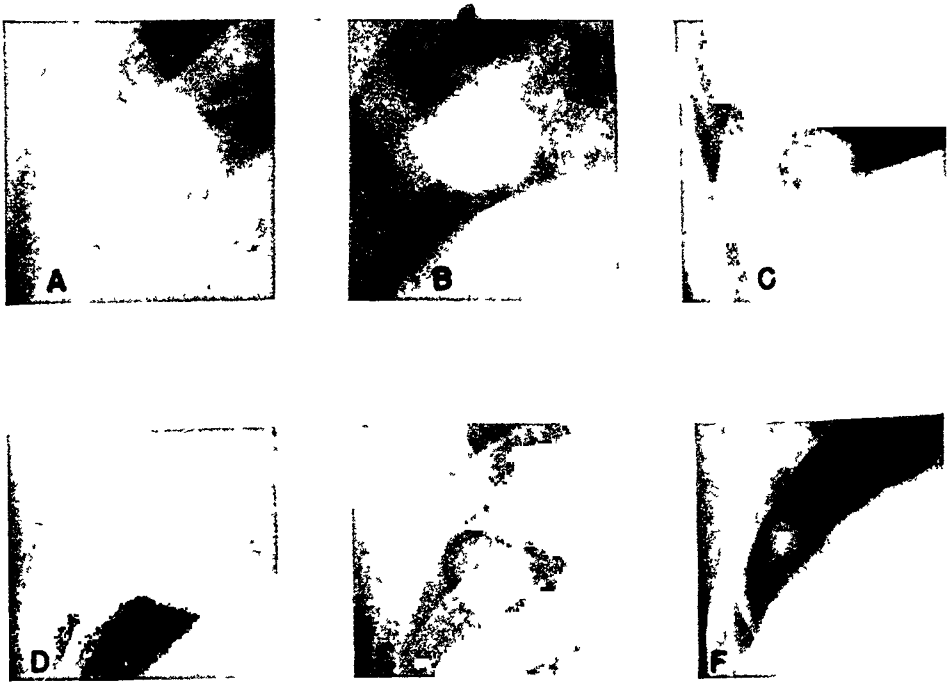

Fig. 14.—Representative plain x-rays of various types of calcification that we consider grounds for observation. *A*, Solidly calcified nodule. *B*, Diffusely calcified nodule. *C*, Nodule with a large calcific core and concentric laminations *D*, Nodule with an extremely large central core of calcium. *E*, Nodule with a large eccentric core of calcium. *F*, Nodule with a moderately large central nidus of calcium When calcification of these types and prominence is demonstrable, we leave the nodule alone unless it increases in size or shows other evidence of instability.

cavitation as an indication of benignity. In fact, out of 18 solitary nodules with cavitation analyzed by Rigler at least 11 proved to be malignant, thus forcing him to the conclusion that the presence of cavitation in a lesion showing no other evidence of an inflammatory process should be considered indicative of a malignant tumor.[15]

i *Satellite nodules:* Although there has been little written on the subject, the presence of small satellite nodules in the roentgenogram provides reasonable assurance that a lesion is benign. Such nodules were radiographically demonstrable in 3 cases in this series, all being granulomas, one containing Coccidioides, another Histoplasma, and the other showing no organisms in specially stained tissue section. Many others, especially among the histoplasmomas, presented small subpleural satellite nodules at operation, but these were seldom well defined in the x-ray. Once again, however, there is no guarantee of benignity, a point emphasized by Overholt and his associates.[77]

Thoracotomy.—In the final analysis the one dependable diagnostic aid, in fact the only uniformly reliable one outside of autopsy, is thoracotomy. Fortunately, this carries as an added dividend the opportunity to excise the lesion which in most instances is the treatment of choice anyway. All patients in our series ultimately came to thoracotomy. This in itself has convinced us of the futility of elaborate preoperative investigations.

The types of operation utilized in our 215 cases are indicated in Table VII. In all cases the magnitude of the resection was dictated by a correlation of the patient's condition, the gross findings at operation, and the results of frozen-section tissue examination. In 8 cases, all of them unresectable carcinomas observed for more than one year prior to surgical consultation, the operative procedure was limited to exploration and biopsy. In all other cases the lesions were resectable, having been treated most commonly by a limited resection if benign, and either pneumonectomy or lobectomy if malignant. As will be pointed out in later discussion of bronchogenic carcinoma, we have come to regard lobectomy as a perfectly acceptable procedure in many of the peripheral carcinomas unassociated with gross lymph nodal involvement. One other aspect of Table VII deserves elucidation and that is the performance of eleven pneumonectomies for benign lesions. This simply reflects the fact that early in our experience we were less adept at distinguishing benign from malignant tumors and considered pneumonectomy to be the only adequate operation for bronchial carcinoma.

Our mortality rate with thoracotomy plus a limited resection (108 cases) has been nil. However, among those with lobectomies and pneumonectomies (107 patients), there have been five hospital deaths, four after pneumonectomy and one following lobectomy, the pathologic diagnosis in each case being bronchogenic carcinoma. Another patient with a large granuloma died at home suddenly and unexpectedly six weeks following pneumonectomy. He too has been included as an operative death bringing the total for the series to six (2.8 per cent).

TABLE VII. OPERATIONS AND OPERATIVE MORTALITY
215 SOLITARY PULMONARY NODULES

LESION	TOTAL CASES	PNEUMONECTOMY	LOBECTOMY	SEGMENTAL RESECTION	WEDGE RESECTION	ENUCLEATION	EXPLORATION AND BIOPSY	DEATHS
Bronchogenic carcinoma	79	39	30	1*	1†	-	8	4‡
Bronchial adenoma	9	4	2	2	1*	-	-	-
Primary sarcoma	2	1	—	1*	—	-	-	1§
Lymphoblastoma	1	1	—	—	—	-	-	-
Metastatic tumor	10	1	2	1	6	-	-	-
Granuloma	82	2	12	3	64	1	-	1‖
Hamartoma	9	1	—	3	3	2	-	-
Mesothelioma	6	1	—	—	4	1	-	-
Chronic pneumonitis	4	2	—	2	—	-	-	-
Bronchial cyst	3	1	—	—	2	-	-	-
Bronchopulmonary sequestration	3	1	2	—	—	-	-	-
Neurofibroma	2	—	1	—	—	1	-	-
Chronic lung abscess	2	1	1	—	—	-	-	-
Lipoid granuloma	1	1	—	—	—	-	-	-
Lymph node	1	—	—	—	1	-	-	-
"Aspergilloma"	1	1	—	—	—	-	-	-
Total	215	57	50	13	82	5	8	6 (2.8%)

*Frozen section—benign.

†Frozen section—metastatic.

‡Three deaths following pneumonectomy; one after lobectomy.

§Died after pneumonectomy.

‖Patient did well postpneumonectomy, but died suddenly six weeks later.

The morbidity rate has been correspondingly low. Early in the series there were five postpneumonectomy bronchopleural fistulas with empyema. All eventually healed following pleural drainage and thoracoplasty. During the last eight years of this study there have been but two empyemas following pneumonectomy and both of them responded well to aspiration plus combined systemic and intrapleural antibiotic administration. There were 2 patients who, after wedge resection of supposedly nonspecific granulomas, developed tuberculous reactivation and required long-term chemotherapy plus completion of the lobectomy. Finally, one other case, following a wedge resection for a nonspecific granuloma, was complicated by a persistent bronchopleural fistula which responded to completion of the lobectomy and long-term antituberculous chemotherapy, the latter despite our failure ever to prove a tuberculous etiology. Except for these cases, all patients did well and were discharged from the hospital on an average of eight to ten days postoperatively.

The absence of any mortality from exploration and limited resection alone, the reasonably low mortality rate following more radical resection and the absence of any appreciable morbidity, except in cases of carcinoma and tuberculosis where it might be anticipated anyway, provides to our way of thinking convincing proof of the safety in exploring every patient with a solitary, noncalcified pulmonary nodule.

PATHOLOGIC ENTITIES

Bronchial Carcinoma.—Besides being the most important single entity included among the solitary pulmonary nodules, bronchial carcinoma rivals the granulomas as the most common. In our series there were 79 bronchial carcinomas (36.7 per cent) as compared with 82 granulomas (38.1 per cent), these two lesions together comprising 75 per cent of total nodules.

Breakdown by cell type is interesting (see Table II) although not differing significantly from accepted figures for peripherally situated carcinomas. Most frequent were the adenocarcinomas, numbering 36 in all, including 9 bronchiolar carcinomas. There were 34 squamous carcinomas. The other 9 were undifferentiated carcinomas. This is decidedly different, of course, from bronchial carcinomas, in general only about 13 per cent of which are adenocarcinomas,[74] but quite in keeping with the work of Walter and Pryce who have shown that primary adenocarcinomas of the lung arise predominantly if not invariably in the periphery.[75] Insofar as survivorship is concerned, the end results are somewhat surprising, for they suggest, though admittedly in figures far short of statistical significance, that the adenocarcinomas and undifferentiated carcinomas have as favorable a prognosis as the squamous variety. Thus, the survivors include 15 patients with squamous carcinoma (44 per cent), 17 with adenocarcinoma (47 per cent), and 4 with undifferentiated carcinoma (44 per cent). We attributed this at first to chance, but note that Belcher recently concluded after an elaborate study that patients with adenocarcinoma amenable to lobectomy have a better prognosis than those with squamous carcinoma so situated as to be suitable for lobectomy.[76] Similarly, undifferentiated carcinomas appeared to him to have not nearly as bad a prognosis when lobectomy was possible as they did when the tumor was more extensive, even to the point that their 2-year survival rate closely approximated that for squamous carcinoma (43 per cent versus 40 per cent).[76]

Where our results were worst was among the bronchiolar (alveolar cell) carcinomas. In our experience these have carried a poor prognosis. All but 3 of our 9 patients with bronchiolar carcinoma have now died or are in the process of dying and 2 of the remaining 3 were resected much too recently (two and four months, respectively) for anyone to guess their ultimate fate. We would agree therefore with those from the Mayo Clinic whose survival rates after resection of these tumors parallel our own.[77] Despite the fact that the bronchiolar carcinomas in our series were mostly small asymptomatic lesions unaccompanied by nodal involvement and upon microscopic examination were better differentiated than the average adenocarcinoma, we have yet to encounter what we would label "favorable bronchiolar carcinoma" as it has been called by Overholt and his associates.[78]

While our over-all results in the surgical management of the malignant solitary nodule are far from ideal, they manifest little of the pessimistic overtones generally associated with bronchial carcinoma. Out of 79 patients in this series having bronchial carcinoma, 34 are still alive in seeming good health, while an additional 2 cases can be justifiably consid[illegible]red by surgery although having subsequently succumbed to other causes. These latter 2 patients were operated upon in their sixties and died in their seventies (one eight years and the other five years, postoperatively) without showing any demonstrable recurrence either clinically or at autopsy. Another patient whose tumor was a squamous carcinoma lived for eleven years following pneumonectomy but died with spinal metastasis and is not included in the group of survivors. As suggested by two independent groups in 1948,[79, 80] there is a reasonably close correlation between the 2- and 5-year survival rates, and it is on this basis that our own survival rates have been calculated. There are then 36 patients (45.6 per cent), who can be regarded as potential "cures," with 17 patients being 3-year survivors, 10 more being 2-year survivors and the remaining 9 patients being less than two years postoperative. This figure is disappointing on the surface, but becomes a good deal more optimistic considering that, of the 43 patients who did not survive, 28 had been observed by their physician for periods in excess of six months and 20 of these had actually had the growth of their nodules checked periodically for over a year.

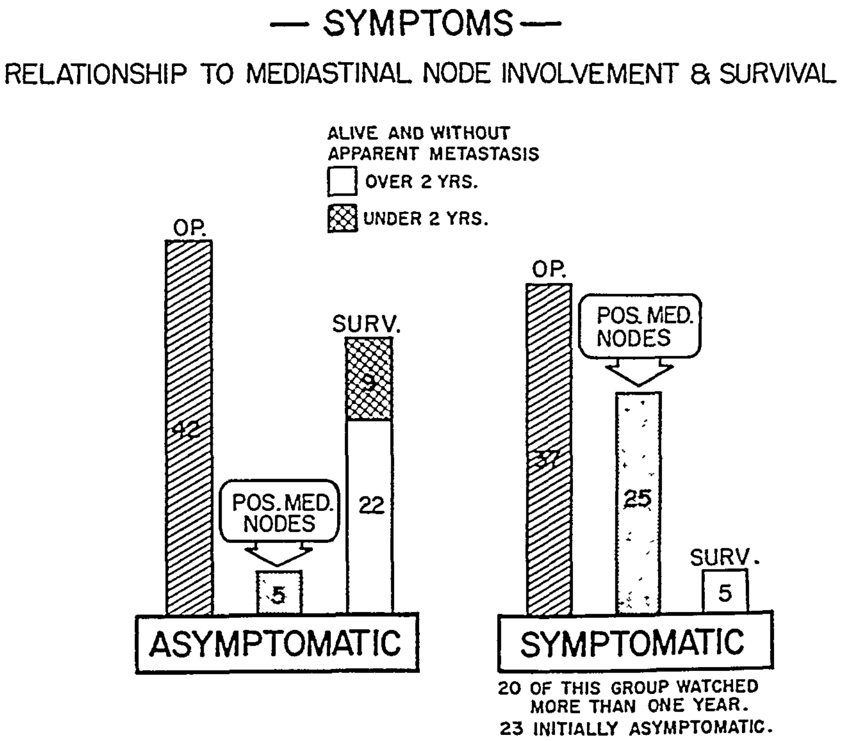

Fig. 15.—Illustration of the prognostic significance of symptomatology both upon mediastinal lymph node involvement and ultimate survivorship.

In other words, many were robbed of a chance for cure long before being referred for surgical consultation.

The presence of symptoms, or preferably their absence, had an impressive influence upon survivorship. Out of the 79 patients with bronchial carcinoma, 65 were asymptomatic when the radiographic density was first detected. As a reflection of the long periods of observation forced upon so many of these patients, an additional 23 developed symptoms before coming to operation Thus, at the time of thoracotomy 37 patients had symptoms whereas 42 had none These are shown in Fig 15 Of the 42 who were symptom free 31 (74 per cent) are surviving in apparent good health without evidence of recurrent carcinoma Admittedly 9 of the survivors are less than two years postoperative but even discounting these there are still 2 survivors out of every 3 patients with solitary circumscribed bronchial carcinomas operated upon in the asymptomatic phase By contrast, among the 37 patients operated upon after the appearance of symptoms only 5 survive (13 per cent)

Moreover, there has been a rather clear cut relationship between the existence of symptoms and mediastinal lymph nodal involvement Whereas only 5 (12 per cent) of those without symptoms showed microscopic evidence of mediastinal lymph node involvement, 25 (67 5 per cent) of the symptomatic group exhibited metastatic tumor in one or more mediastinal lymph nodes and 8 of these were unresectable Conversely, the asymptomatic lesions were uniformly resectable The relationship of symptomatology to both mediastinal node involvement and survivorship is illustrated in Fig 15 These findings are in general agreement with other reports on asymptomatic bronchial carcinoma,[3, 51] at least in the broad sense that the asymptomatic lesion has a higher rate of resectability and a potentially higher rate of curability

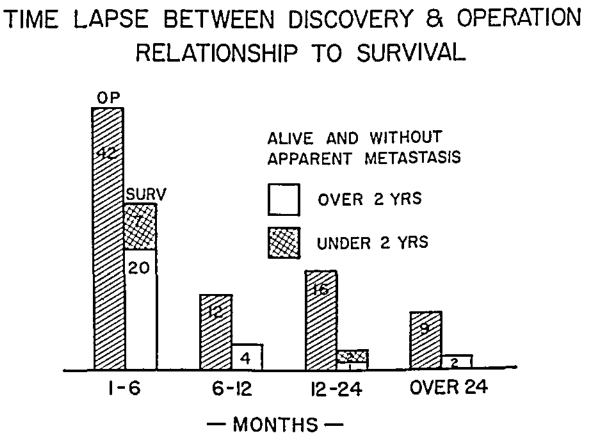

Fig 16—Illustration of the influence upon survivorship of the time lapse between detection and resection of the nodule.

than symptomatic carcinoma of the lung In our experience this difference has been impressive enough to constitute a telling argument in support of routine and survey chest roentgenograms of asymptomatic patients

An analysis of the time lapse between discovery of the lesion and operation and its relationship to survival is shown in Fig 16 Forty two of the 79 patients with bronchial carcinomas were operated upon within six months after roentgenologic detection of the lesion. Twenty-seven of this group (64 per cent) survive in apparent good health without evidence of metastasis. When operation was delayed six months to a year only 4 (33 per cent) out of 12 patients survived and when delayed over one year 5 (20 per cent) of 25 survived. Interestingly enough, there were 2 patients who are alive and well three and six years after resection despite having been observed preoperatively by their physicians for two and three years, respectively. Still another patient was followed for three years before being referred for surgery. He was alive and well when last heard from four years postoperatively, but he was subsequently lost to follow-up and has not been counted as a survivor. Nevertheless, these 3 cases demonstrate the indolence and relatively low biologic activity of an occasional carcinoma of the lung. More often than not the opposite tends to be true, however; hence the need for prompt excision seems inescapable; the sooner the resection the better the chance for cure. Our experience leads us to believe that the small solitary circumscribed asymptomatic bronchial carcinoma recently picked up in a fortuitous chest roentgenogram, an admittedly small segment of all bronchial cancer unfortunately, has a good chance for complete eradication if operated upon promptly. Thirty-two of our patients fall into this category and 24 (75 per cent) survive in apparent good health. Out of this group there were 14 operated upon over five years ago and 11 (78 per cent) are alive and well today. While the number of cases quoted is much too small to assume statistical significance, it suggests that the 5-year survival rate in bronchial carcinoma so situated and so handled approaches 75 per cent.

Finally, it is highly significant, we feel, that the extent of surgery (pneumonectomy versus lobectomy) does not appear to have any significant effect upon the ultimate survival of certain cases and we now regard lobectomy as a perfectly sound and adequate cancer operation in properly selected cases, the chief requirements being a well-circumscribed lesion, peripherally situated and free of gross lymph nodal involvement. As far back as 1934, the Mount Sinai group[82] pointed out the singular behavior of these tumors and made reference to their suitability for lobectomy, but like many another concept too far ahead of its time this proposal met with much undeserved abuse each time it was reintroduced.[79, 83] Subsequent comparisons of survival rates for lobectomy as opposed to pneumonectomy[76, 84-89] clearly vindicate their contention, however, as does an analysis of our own cases.

The surgical procedures performed on the 79 patients with bronchial carcinoma consisted of pneumonectomy 39 times, lobectomy 30 times, biopsy 8 times, and limited resections twice, the latter having been prompted by erroneous frozen-section diagnoses (Table VII). Of the 36 survivors, 20 had had pneumonectomies and 16 had had lobectomies, in other words about one half of the original pneumonectomies and one half of the lobectomies survive. Among those treated by pneumonectomy, 12 are living and well more than five years postoperatively, 5 between two and five years postoperatively, and 3 less than two years postoperatively. Among the lobectomies 5 are 5-year survivals, 5 more are 2 year survivals, and 6 are not yet two years postoperative. To us the feature of greatest significance is the fact that those who died of recurrent carcinoma following lobectomy died not of local recurrence but from generalized metastases, most frequently cerebral. Thus the trend in our management of these patients has changed from routine pneumonectomy to lobectomy whenever feasible. When no gross evidence of lymph node involvement has been noted and the lesion was confined to the periphery of a lobe, our results with lobectomy have been as good as those with pneumonectomy.

On the other hand, we do not mean to imply that lobectomy is a satisfactory substitute for pneumonectomy in less favorable situations. When the tumor encroaches upon the hilus or when enlarged hilar or mediastinal lymph nodes are present, we consider pneumonectomy to be the treatment of choice. Nevertheless, as pointed out by Boyd and his co-workers,[81] a fairly radical lobectomy can be performed, especially in upper lobectomy, and it is thought-provoking to find Belcher[76] stating that further elucidation of the lymphatic drainage of the lung "may show that it is as irrational to recommend pneumonectomy for an upper lobe tumour as it would be to remove the entire colon for carcinoma of the sigmoid." Regardless of additional refinements in technique that may eventually appear, it seems clear to us at this point that lobectomy very definitely has a place in the management of the primary malignant solitary nodule, carrying with it a considerable reduction in operative mortality and preservation of pulmonary function without significantly reducing the chance for long term survival.

Bronchial Adenoma.—As far as bronchial adenomas are concerned only two features require comment here. First is the question of their malignancy; second, their not infrequent though seldom appreciated tendency to arise peripherally.

That they are all potentially malignant is well known. To be convinced of this one has but to witness the lymphatic and sometimes more extensive metastases associated with a perfectly benign looking tumor, or run into a recurrence following local excision of an apparently benign lesion or encounter frank carcinomatous transformation in an otherwise benign adenoma. Considering how difficult it may be to prove the origin of a carcinoma from an adenoma, this last possibility may occur more commonly than we think. For these reasons we personally regard all bronchial adenomas, be they carcinoids or cylindromas, as low-grade adenocarcinomas having an exceedingly favorable outlook if excised early but a guarded and oftentimes fatal prognosis if neglected indefinitely. Since no one would dispute the need for their excision, it seems justifiable to classify them as malignant lesions. However, we have not gone so far as to lump the adenomas in with the carcinomas for fear someone might infer that the high incidence of bronchial carcinoma among our solitary nodules might be due to artificial padding. Actually the opposite is true, because several lesions originally thought to be bronchial carcinomas were reclassified as adenomas after reviewing the histologic sections as a part of this study.

The other point, that is, the chance of their assuming a peripheral position also deserves emphasis, for in the popular mind the typical adenoma is a central obstructive tumor not a peripheral solitary nodule. Nevertheless, about 10 per cent will arise far enough peripherally to present the radiographic appearance of a solitary nodule.[90] Nine nodules in our series turned out to be bronchial adenomas, an incidence of 4 per cent which is somewhat higher than that in most series but only one half that reported from the Mayo Clinic.[11]

Surprisingly, 5 of the adenomas in our series occurred in men and only 4 in women. There were 6 carcinoids, 2 cylindromas, and one well-differentiated mucous gland adenoma.[91] There was lymph node involvement in but one case, and all 9 patients remain alive and well for periods ranging from two to eleven years.

Rare Primary Pulmonary Malignancy.—There is little need to expound upon the many malignant tumors that arise occasionally in the lung and still less commonly present as a solitary nodule. Representative examples such as a fibrosarcoma, a leiomyosarcoma, and a lymphoblastoma are included in our series. The subject of bronchopulmonary sarcomas has recently been comprehensively covered with special attention to their rarity, peripheral location, predominance in middle-aged persons, difficulties in pathologic differentiation, and amenability to surgical excision.[92] A number of entities both malignant, such as, oat-cell and pleomorphic-cell carcinoma, and benign, for example, postinflammatory pseudotumors,[93] are apt to be mistaken for pulmonary sarcomas thus emphasizing the need for the greatest of care in microscopic interpretation. The one fibrosarcomatous nodule in our series occurred in a 51-year-old man. The lesion had enlarged slowly over a 3-year period of observation, yet there was no evidence of nodal involvement at pneumonectomy. To our dismay he died forty-eight hours postoperatively of undetermined cause. The patient with a leiomyosarcoma was a 52-year-old man who remains in good health five years postoperatively despite a very limited resection imposed by the frozen-section tissue diagnosis of a benign lesion. The third patient was a 39-year-old woman who had a pneumonectomy for a lesion diagnosed as a lymphoblastoma. There was no lymphatic metastasis. X-ray therapy was withheld pending the appearance of metastases which to our amazement have not yet appeared. She remains in good health eleven and one-half years later and represents as far as we can determine[94] the longest surviving case of resected primary pulmonary lymphoma on record.

Metastatic Malignancy.—Ten of the solitary nodules in our series proved to be metastatic to the lung. All but 2 of the patients had had prior cancer surgery anywhere from one to twelve years earlier. In each of these cases, the possibility that the pulmonary nodule represented a solitary metastasis was seriously considered, yet on the other hand there were 3 more patients who had had a primary extrapulmonary carcinoma resected previously, all 3 of whom turned out to have a separate primary carcinoma of the lung. This then is the chief reason for advising prompt thoracotomy in a patient with a solitary pulmonary nodule and a history of a previously excised malignancy. Admittedly, the likelihood of finding a metastatic nodule stands high, but not high enough to invalidate the possibility of a primary bronchial carcinoma, especially when the interval between operations is relatively long.

The merits of resecting metastatic pulmonary nodules are dubious at best. When there is but one demonstrable metastasis, however, its excision may be worth while, achieving definite prolongation of life in some instances and less frequently a long-term survivor, the classic example being a patient with a hypernephroma whose case was reported by Barney and Churchill[95] in 1939, with a 9-year follow-up after resection of a solitary metastatic deposit in the lung. The essential requirements, of course, are a reasonable assurance that the primary malignancy has been controlled and the inability to demonstrate more than one site of metastasis. Ideally, an adequate interval of time, preferably three years or so, should have elapsed between operations for the primary and secondary lesions. But the logic in delaying the second operation to see whether additional metastases shall appear is apt to be nullified by the fact that the nodule may be primary rather than metastatic. Moreover, in a superb analysis by Seiler and his associates,[96] it could only be concluded that contrary to expectations the patients with a long hiatus between the two operations did no better than the group as a whole.

Needless to say, the cell type and organ of origin are other factors influencing the chance for cure, although these too are in no sense reliable. Generally speaking the outlook for those due to carcinoma of the skin, cervix, colon, kidney, ovary, and breast is probably better than for those from other locations.[97] Likewise the prognosis is possibly more favorable for metastatic sarcoma than for metastatic carcinoma.[98, 99] When all is said and done, however, the chance for complete eradication is extremely remote. Characteristically, once a secondary tumor appears, widespread metastases are usually soon to follow. This is exemplified by one of our patients who, after nephrectomy for hypernephroma, survived twelve years before a metastatic nodule appeared in the lung, only to have signs of cerebral metastasis arise within one month after pulmonary resection.

Of the other 9 patients, 2 had no previous history of carcinoma and the primary sites were detected only after microscopic recognition of the metastatic nature of the pulmonary lesion. Neither of these patients survived more than two years. This particular situation, operation upon the metastasis prior to the primary malignancy, was so rarely encountered in our series that there would seem to be little justification for an elaborate search for a primary extrapulmonary tumor in the preoperative study of the indeterminate solitary pulmonary nodule. Without some clue to a primary elsewhere the direct approach to the pulmonary lesion would seem more logical, less time consuming and perhaps less expensive in the long run.

In our series of metastatic pulmonary tumors the survivorship has been rather dismal although not entirely discouraging. Only 4 patients are still alive. Two (colon and breast) have recurrent carcinoma twenty-one and fourteen months following thoracotomy. The other 2 (breast and osteogenic sarcoma) are living in apparent good health without evidence of further metastasis fifty-eight and forty-three months, respectively, after resection of a solitary pulmonary metastasis.

Granuloma.—In practically every series of solitary pulmonary nodules the most common single entity has been the granuloma. Thirty-eight per cent of our series were granulomas as were 41.6 per cent of nodules reported in other series (see Table I). They account for by far the bulk of the benign nodules. Traditionally these lesions have been called "tuberculomas," an etiological assumption usually based on nothing more than their gross appearance. Even when soft or cavitary, such granulomatous foci more often than not are negative for acid-fast bacilli both culturally and histologically and when the nodule is old and laminated, and especially when partly calcified, the bacteriologic yield is almost negligible. Even then, if the only positive skin sensitivity test is the tuberculin, a presumptive diagnosis of a tuberculoma might be justified, but for one to incriminate a tuberculous origin in the face of a negative skin test is a precarious position indeed. Hence it should take only one large series like Mahon and Forsee's,[43] in which 30 per cent of the "tuberculomas" were accompanied by a negative tuberculin skin test, to convince one that another organism might be responsible for some of these infections.

TABLE VIII. 82 GRANULOMAS (RADIOGRAPHICALLY NONCALCIFIED)

Studied by special stains		71
Tuberculoma	12 (17%)	
Histoplasmoma	39 (55%)	
Histoplasmic lymph node	1	
Coccidioma	5 (7%)	
Diagnosed	57 (80%)	
Nonspecific	14 (20%)	
(possible Histoplasma, 2; possible Cryptococcus, 2)		
Not studied		11
(tissue not available)		
Total		82

Actually the idea that fungi might produce lesions indistinguishable from the so-called tuberculoma is by no means new. As far back as 1915, Coccidioides were demonstrated in such a nodule,[100] but it was not until 1939 that Cox and Smith[101] called special attention to the "arrested pulmonary coccidioidal granuloma." Since then the coccidioma has been thoroughly restudied by various investigators[102-106] who have established both its prevalence and its pathologic significance.

In contrast to the coccidioidal residual in which sporangia can almost always be identified if a persistent microscopic search is made of hematoxylin and eosin-stained sections, proof of the histoplasmic etiology of comparable lesions has been greatly delayed by the infinitely greater difficulty in demonstrating Histoplasma in quiescent, presumably inactive foci. Only by the recent development of more sensitive tissue stains has identification of the organism been possible in such cases. Using the periodic acid-Schiff (PAS)

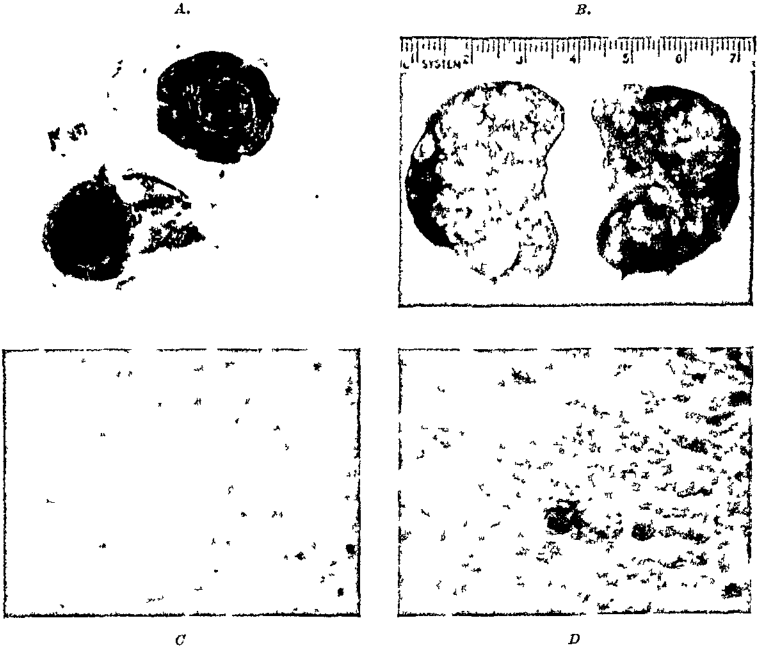

Fig. 17.—The residual histoplasmic focus.

A, Transected specimen of a typical histoplasmoma showing the characteristic pleural plaque, concentric laminations and necrotic center.

B, Transected bronchial lymph node that presented as a pulmonary nodule (see Fig. 7) and appeared grossly granulomatous. Special stains revealed myriads of Histoplasma.

C, Hematoxylin and eosin-stained tissue section from a so called "tuberculoma" showing nothing but coagulation necrosis.

D, The very next section stained by the periodic acid Schiff method and centered on the same microscopic field seen in *C*, discloses an impressive number of typical Histoplasma.

stain Puckett[10, 108] was able to identify Histoplasma in 22 resected granulomas all of which fit the gross and microscopic picture of healed tuberculomas This highly significant finding has been adequately confirmed by Zimmerman,[109, 110] Binford,[111] one of us,[11] and in a subsequent report by Puckett,[113] but to date has gained little acceptance by the majority of pathologists, most of whom retain the erroneous notion that routine staining methods are quite adequate for the demonstration of fungi We readily concede that in active lesions, particularly in the presence of progressive disease, the ordinary hematoxylin and eosin stain is quite satisfactory for diagnosing the deep mycoses However, in mild, healing, or "burnt out" infections fungi are apt to stain poorly if at all by this method[114] and require a special stain such as the PAS, Gridley,[115] or methenamine silver nitrate[116] for their demonstration This point can be conclusively proved by a comparison of identical tissue sections stained by different techniques (Fig 17) In the hematoxylin and eosin stained section taken through the central necrotic zone of a pulmonary granuloma, no organisms are visible In striking contrast the very next section from the same paraffin block discloses a vast number of typical Histoplasma when stained by the PAS method Inasmuch as other mycoses such as cryptococcosis[1, 13, 117] and on rare occasions blastomycosis[106, 118, 119] and even geotrichosis[106] and mucormycosis[1 0] have also been incriminated as a cause of a "tuberculoma," we were extremely anxious to investigate this aspect of our granulomas

An attempt was made to obtain the paraffin tissue blocks of all granulomas included in this series This was possible in 71 cases Multiple sections were then recut and at least nine stained slides, three with the Ziehl Neelsen stain, three with the PAS stain, and three with the Gridley stain were meticulously reexamined Histoplasma were clearly seen in 40 cases, one being a lymph node, Coccidioides in 5 cases, and acid-fast bacilli in 9 However, in three additional instances, the tuberculous nature of the infection was proved by recovery of tubercle bacilli in culture, once from the resected specimen and twice from the sputum when the process recurred postoperatively in the operated lobe (Fig 18) Thus, 12 granulomas were true tuberculomas In 4 other cases forms suspicious but not diagnostic of Histoplasma (twice) and Cryptococci (twice) were seen, but because of insufficient evidence these, along with 10 other cases in which no organisms were seen, are classed as nonspecific granulomas As shown in Table VIII a positive diagnosis was possible in 80 per cent of the cases studied The largest percentage of these, 55 per cent of the total number studied, were histoplasmomas, while another was a histoplasmic lymph node Seventeen per cent of those studied proved to be tuberculomas and 7 per cent were coccidiomas Another six resected specimens that are not included in our series of solitary nodules because they contained calcium were also shown to be histoplasmomas (see Table V) It becomes quite obvious therefore that the majority of pulmonary granulomas, instead of being tuberculous, are actually mycotic in origin Additional study is indicated to determine the etiology of the as yet undiagnosed granulomas, some of which are undoubtedly silicotic[48] while others, such as 2 reported cases caused by brucella,[63] must result from bacteria other than the tubercle bacillus

The prognostic significance of these granulomas is difficult to assess. A number of publications suggest that the tuberculomas warrant excision because of the constant threat of reactivation. Barring the cavitary and the soft exudative lesions, we are not so sure this is necessarily true; hence our willingness to observe the partially calcified pulmonary nodule. In a paper frequently quoted as an argument in favor of resection, Mitchell[121] concluded that with prolonged observation of a solitary dense tuberculous pulmonary focus there was about one chance in four of progression of the disease when untreated by resection or chemotherapy, but severe progression was rare and none proved fatal. Moyes[122] demonstrated an even higher rate of instability than Mitchell but showed a better ultimate prognosis and the only death in his series resulted from a bronchopleural fistula following resection. Moreover, as Macleod and Smith point out, "We must be chary of too ready acceptance that the round focus is responsible for the spread of disease. All patients with tuberculous disease are liable to break down. The round and apparently solitary focus is so frequently accompanied by other tuberculous foci in the lung that these radiologically invisible lesions may well be the source of bacilli."[123] In what is undoubtedly the most painstaking study yet conducted on this problem, Hillerdal[124] was impressed by the favorable long-term prognosis among patients with untreated tuberculomas. Bronchogenic spread was uncommon. When it did occur, the disease in every instance was easily controlled by chemotherapy and involved no great danger to the patient. Two factors account for the frequency with which such nodules need to be

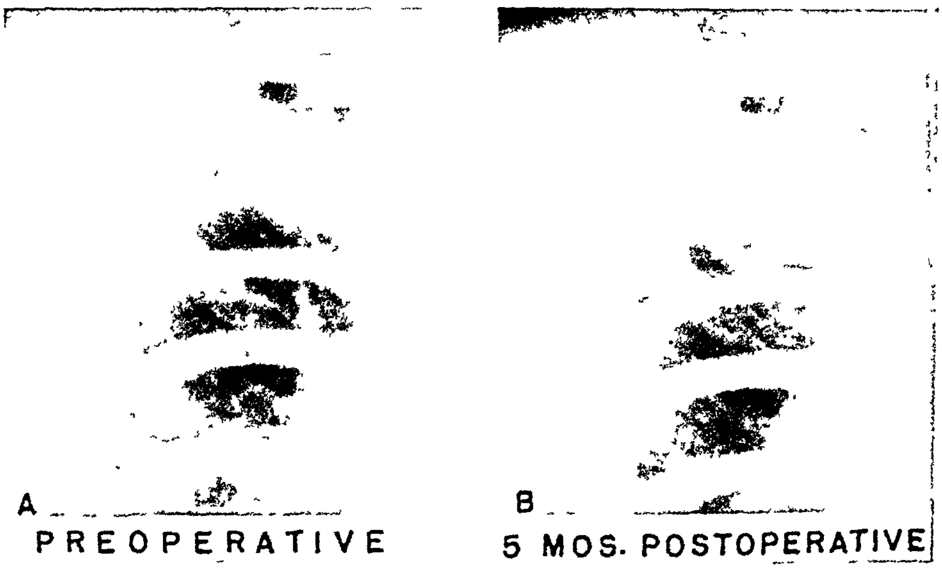

Fig. 18.—*A*, Preoperative x-ray of a patient with a solitary nodule in the right first anterior interspace Tuberculin and histoplasmin skin tests were both positive. Sputum and gastric washings were negative for acid-fast bacilli. Neither AFB nor fungi could be demonstrated in the wedge-resected granuloma. No chemotherapy was given. *B*, Roentgenogram taken five months postoperatively reveals a cavitary lesion at the operative site at which time sputum was positive for AFB. Patient required chemotherapy and completion of the lobectomy.

This and another case like it convince us of the necessity of treating every nonspecific granuloma with antituberculous chemotherapy whenever the tuberculin skin test is positive. If, on the other hand, the tuberculin test is negative or if fungi can be demonstrated in the necrotic center, additional treatment would not seem to be necessary.

excised, however, these being the inability to rule out malignancy in the recently discovered tuberculoma and the possibility that it is a blocked cavity when serial x-rays show it to be the residual of more extensive, previously treated disease. Even so, whenever calcification can be seen within the nodule, trouble from either of these two possibilities is so remote that we regard medical observation as the logical course to follow.

In the case of the solitary mycotic foci we are still more certain of the advisability of leaving them alone, provided of course that malignancy can be ruled out. The occurrence of cavitation within the solid coccidioidal residual is not common and is even less likely to occur in the histoplasmoma. Dissemination from such a nodule is almost unheard of, although alluded to on at least one occasion.[124] Perhaps the best reason for not expecting any trouble from these focalized fungal infections is the questionable viability of the organisms as manifested by the great difficulty in culturing anything from the specimen. Although one writer infers that their recovery can be anticipated,[125] our own experience bears out that of Puckett,[107] in that only once have we been able to culture *H. capsulatum* from one of these histoplasmonas, and never have we had a recurrence regardless of how limited a resection was done. The fact that these healed mycotic foci are so innocuous as well as the fact that they represent a substantial portion of the partially calcified nodules seems to us to provide additional justification for a program of observation in the case of the solitary nodule containing unequivocal radiographic evidence of calcification.

When neither acid-fast bacilli nor fungi can be demonstrated in the specimen, a dangerous sense of security may develop. In such a situation we twice permitted an avoidable recurrence by failing to have proper respect for the possibility of tuberculosis (see Fig. 18). Both of these patients had limited resections; both had positive tuberculin and histoplasmin skin tests; neither received antimicrobial chemotherapy following operation and both developed recurrence in the remainder of the involved lobe. Although each of these patients is recovering after prolonged chemotherapy plus completion of the lobectomy, the use of prophylactic antituberculous chemotherapy postoperatively would in all likelihood have obviated a second operation. As a result of this experience we are convinced that, provided the tuberculin skin test is positive, the granuloma in which neither acid-fast bacilli nor fungi can be demonstrated deserves at least six months' antituberculous drug therapy as a precautionary measure.

Hamartoma.—Hamartomas are generally regarded as rare pulmonary tumors, when in reality they are probably not too uncommon. In the Mayo Clinic series,[11] for example, hamartomas were as common as bronchial carcinomas, comprising 16 per cent of all their solitary nodules. We have encountered only 9 in our series and 2 of these were resected from the same patient in operations performed five years apart.

Regarding hamartomas, easily the outstanding question at the moment concerns the widely accepted view that these tumors are always benign. Simon and Ballon[126] are often referred to as the only ones to report malignant hamartoma, and in that case the diagnosis rested solely on marked cellular proliferation and capsular invasion within the nodule. Recently there appeared a case report of a pulmonary osteochondrosarcoma that probably arose in a partly calcified hamartoma[127] and another report of a malignant hamartoma was published abroad.[128] In answer to our question about malignancy arising in a partly calcified nodule, 2 malignant hamartomas were cited (see Table VI), the one by Ballon referred to above,[127] and another by Effler, as yet unreported. We have also learned from Klepser[129] that he too has excised a malignant hamartoma containing cartilage but no calcium. There seems to be little doubt therefore that malignancy can arise in the hamartoma, although it is apparently seldom that it does so.

Pleural Mesothelioma.—The solitary fibrous type of pleural mesothelioma commonly creates the radiographic impression of a pulmonary nodule although in truth it is extrapulmonary. One of the major problems in categorizing the various solitary pulmonary nodules is the difficulty in differentiating localized pleural mesotheliomas from fibromas, fibrosarcomas, neurofibromas, and neurofibrosarcomas, for any of which they are apt to be mistaken. Clubbing of the digits and arthralgia are frequent accompaniments of this tumor but were noted in none of the mesotheliomas in this series, due perhaps to the fact that the large mesotheliomas with which arthropathy is more apt to be associated[130] are excluded from this study. Even when present such signs provide no help in ruling out bronchial carcinoma. Moreover, regardless of their benignity, mesotheliomas warrant excision on their own merits owing to the tremendous size they may ultimately achieve.

Unresolved Pneumonitis and Abscess.—On a few occasions chronic inflammatory processes will take the shape of a fairly well-defined pulmonary nodule. Since they are likely to be accompanied by symptoms such as hemoptysis (see Table IV) and because the margin of this kind of nodule is apt to be a little fuzzy, the resemblance to a carcinoma may be more striking than will the average nodule.

Bronchogenic Cysts.—Those bronchogenic cysts unassociated with a bronchial communication can distend with mucus or pus and thus assume the appearance of a pulmonary nodule. It was of interest to us that out of 6 such cysts that we have encountered, closer scrutiny showed 3 to have an anomalous blood supply from the aorta, thus throwing them into the category of intralobar bronchopulmonary sequestration (see Fig. 7).

Rare Primary Benign Pulmonary Lesions.—The benign pulmonary lesions that in rare instances will present as a solitary pulmonary nodule are almost too numerous to mention. They include an occasional neurofibroma, fibroma, hemangioma, arteriovenous fistula, leiomyoma, lipoma, and even thymoma. Once again, histologic differentiation may be quite difficult, as witness a recent report on sclerosing hemangiomas of the lung in which the question is raised as to whether some lesions heretofore classified as xanthomas, granulomas, or postinflammatory tumors may not in reality represent sclerosing hemangiomas.[131] There is little doubt that there is room for improvement in our pathologic interpretation of many of these nodules, as is illustrated by one of our earlier nodules that had been originally interpreted by the pathologist as an infarct and was so labeled until recently when the application of special stains showed it to be a histoplasmoma.

Almost without exception we have found something interesting and instructive in each of the solitary pulmonary nodules in this series.

SUMMARY

This report represents the culmination of a study initiated in 1946 concerning the significance of the solitary pulmonary nodule. Our own series of 215 personally resected, noncalcified pulmonary nodules correlates well with the literature in illustrating both the strong malignant propensity of these nodules as well as the improbability of distinguishing the benign and the malignant lesion by any means short of thoracotomy.

Thus in our series, 47 per cent were malignant, 37 per cent being bronchial carcinomas. Clinical, laboratory, and roentgenologic data have been elaborately analyzed without finding any sign reliable enough to justify medical observation, unless it be calcification within the nodule. After polling the members of The American Association for Thoracic Surgery on this highly controversial issue, namely, the reliability of calcification as an indication of benignity, we are convinced that minimal calcification within a solitary pulmonary nodule, especially when no more than a fleck or two, is unjustifiable grounds for assuming it to be benign. There remain certain patterns of calcification that render the possibility of malignancy so slim, however, that further observation seems warranted. These include those nodules with a large central calcific core and diffuse calcific stippling, those with an inner ring or outer rim of calcium and, of course, those that are completely calcified.

In this survey the two groups deserving the greatest attention were the bronchial carcinomas and the granulomas which together comprise 75 per cent of total nodules. Our primary concerns have been the prognosis of the primary carcinomatous nodules and the etiology of the granulomas.

In determining survivorship of those with bronchial carcinoma, cell type appeared to have far less influence than did either the presence of symptoms or time lapse between radiographic discovery of the lesion and operation. Our findings indicate that the small solitary circumscribed asymptomatic bronchial carcinoma recently detected in a fortuitous chest x-ray has a 75 per cent chance of surviving five years if operated upon promptly. Lobectomy appears to be an adequate cancer operation in properly selected cases.

Early in this study, all of the solitary granulomas, because of their gross appearance if nothing else, were presumed to be "tuberculomas." Re-examination of the tissue blocks in these cases by special staining techniques has been most revealing. Fifty-five per cent of the granulomas studied contained Histoplasma and 7 per cent, Coccidioides, in contrast to but 17 per cent in which a tuberculous etiology could be established. The implications of these findings have been discussed in detail as have the various other types of solitary pulmonary nodules.

We can only conclude that every solitary, noncalcified pulmonary nodule demands thoracotomy, that for those with bronchial carcinoma the absence of symptoms and promptness of surgery are apt to determine the chance for cure, and that careful histologic study of the pulmonary granulomas will reveal the majority to be of fungal rather than tuberculous origin.

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Discussion

DR. DONALD L. PAULSON, Dallas, Texas.—I rise only to present our figures for the survival rates on patients who have had pulmonary nodules due to bronchogenic carcinoma.

(slide) This illustrates the distribution of tumors in 180 pulmonary nodules which Dr. Shaw and I have seen in the last ten years; there were 88 tumors and some 62 of those were due to bronchogenic carcinoma, an incidence of 34 per cent.

(slide) If we are to discuss the indications for removal with a medical man and insist upon removal of most indeterminate pulmonary nodules, it is important that we be able to quote our statistics as to survival rates. This slide deals with 24 pulmonary nodules due to bronchogenic carcinoma which are asymptomatic, and reveals a 75 per cent survival rate for two years or more after resection.

(slide) This deals with 41 symptomatic lesions, in contrast to the first slide, and we see the survival rate drop from 75 to 38 per cent for a period of two years or more after resection for those nodules associated with symptoms.

(slide) This is a combination of the two groups; in the entire group, whether or not the nodule was associated with symptoms, the survival rate is 50 per cent for two years or more after resection. There were no surgical mortalities. Six of 14 patients have survived five years or more after resection.

DR. ADRIAN LAMBERT, New York, N. Y.—This is an extremely important study and it is especially timely to call attention again to the importance of exploring these peripheral solitary nodules for the possibility of carcinoma of the lung. I would like to congratulate Dr. Davis on his work in this respect.

I should like to discuss briefly the factors influencing survival rate in these solitary pulmonary bronchogenic carcinomas. There are two factors that determine the survival rate in these tumors. The first is whether they are blood-borne in their metastasis, and the second is whether they spread via the lymphatics. If blood-borne metastasis has already occurred at the time of exploration, I do not think that anything the surgeon does is going to influence the survival rate. On the other hand, if extension occurs via the lymphatics, I think the determining factor is whether the involved lymphatics are going to be removed. For some time I have emphasized the importance of radical mediastinal lymph node resection for carcinoma of the lung. It is difficult at present to evaluate results of resection mainly for one reason. This is, that at the time of exploration these nodes are not catalogued and are not identified for the pathologist, so that when one evaluates the survival rate he may say such and such a number of nodes was involved, and such a group was not. In resection for mediastinal involvement, I think one should remove the right and left bronchial nodes, the carinal nodes, and, by and large, the paratracheal nodes on each side, and send them to the pathologist to be identified as such, so that when the patient comes back you will be able to evaluate the patient's survival with the extent of mediastinal involvement. In this respect, I should like to call attention to one other fact; that these lymphatic chains when blocked with tumor cells, will result in a flow of tumor cells to the other side in reverse direction, either to the upper lobe from the lower, or the lower lobe from the upper lobe, which is not usually mentioned in the description of lymphatic drainage by Poirer and Charpy and other authors.

I want to again thank Dr. Davis for his fine presentation.

DR. PEABODY (Closing).—I wish to thank the discussants and at the same time express our regrets that some of those who answered our questionnaire did not come forward to present examples of partially calcified solitary nodules that turned out to be malignant So far as we personally are concerned, there is adequate justification for the conservative management of the partially calcified nodule, provided of course the calcification consists of more than a mere fleck or two Granting that 150 odd malignant lesions containing calcium were reported by members of the Association, a careful analysis of these reports showed that the majority were minimally calcified, and only a few presented extensive calcification In other words, we tend to agree with Duane Carr, who replied in this fashion, "Recognizing the fact that calcium does not absolutely rule out malignancy, its presence within a malignant solitary nodule is so rare that the chance of its being benign is better than the probability of cure by resection if malignant" One thing that was not mentioned, we would certainly like the patient to have a positive skin test for one of the three major granulomatous diseases before agreeing to pursue a nonoperative plan of management At the other extreme, we are thoroughly convinced of the danger in watching the minimally calcified nodule Observation of such lesions was almost unanimously condemned by those answering our questionnaire, a point that needs to be emphasized to the internist

Having expressed ourselves so emphatically on a subject still far from settled, it is our hope that those who feel differently will report their experiences for, as we see it, this entire issue is the most important question confronting the chest man today

One of the more interesting aspects of the problem is the matter of the mycoses, several features of which deserve clarification or re emphasis For instance, Dr Davis made mention of the fact that the West Coast does not have a corner on the coccidioidal market To be completely honest about it, I must add that all our patients with coccidiomas gave a history of having been in the endemic zones, although in some instances it was for only a very brief period of time By the same token, however, one does not have to visit the Mississippi Valley to contract histoplasmosis which, next to carcinoma of the lung, is probably one of the more common specific diseases we see in the District of Columbia This includes, of course, histoplasmosis in an exceedingly broad radiographic spectrum

(slide) For example, this shows four radiographically indistinguishable nodules Two are bronchial carcinomas, one represents intralobar bronchopulmonary sequestration and the other a histoplasmic lymph node Although all four lesions are close to the hilus, the lateral view showed them to lie either anteriorly or posteriorly, so they are included in our series of pulmonary nodules

(slide) This is the lymph node which appeared typically tuberculous but was teeming with Histoplasma They can be a cause of almost any pulmonary picture including bronchiectasis, atelectasis, middle lobe syndrome, and so forth Dr Higginson this morning got into the subject of mediastinal granulomas in his paper on superior vena caval obstruction Out of twelve resected mediastinal granulomas at the National Naval Medical Center, I have found Histoplasma in 4 of the lesions and 2 others had violently positive histoplasmin skin tests Pathologists still manifest a firm reluctance to accept special staining methods for the demonstration of fungi (slide) These are Histoplasma as seen in the methenamine silver nitrate technique of Gomori, a method with which we have had no experience but one about which Dr Lorenz Zimmerman of the Armed Forces Institute of Pathology is extremely enthusiastic

The final point of our paper concerns the favorable prognosis of peripheral bronchial carcinomas unaccompanied by symptoms and operated upon promptly Survivorship in this group ranges around 75 per cent, a figure that coincides exactly with the one that Dr Paulson has quoted for this series! Unfortunately, his splendid paper (Minnesota Med 39 127, 1956) appeared too late for inclusion in our review for the literature Also, as the Mount Sinai group has repeatedly tried to bring out in the past and as Dr Jones's group re emphasized yesterday, lobectomy seems to be a perfectly acceptable cancer operation in properly selec

PULMONARY RESECTION FOR TUBERCULOSIS

A Five- to Ten-Year Follow-up Study

James D. Murphy, M.D., Baltimore, Md., and James M. Davis, M.D.
(by invitation), Jacksonville, Fla.

THE high morbidity and mortality rates associated with excisional therapy for pulmonary tuberculosis had resulted in virtual abandonment of that means of treatment prior to 1943. Its revival, stimulated by the report of Churchill and Klopstock[1] and later by the discovery of the bacteriostatic effect of streptomycin, is well known to those interested in thoracic surgery.

At the beginning of the chemotherapeutic era we,[2] as well as others, were impressed by the favorable early results obtained when the lesions of pulmonary tuberculosis were resected under the protection of streptomycin. It was generally agreed, however, that final evaluation of this means of therapy could not be made until a five- to ten-year follow-up study of these patients had been completed. We now have such a study on 148 patients who underwent 150 pulmonary resections during the years from 1946 to 1950.

MATERIAL AND OBSERVATIONS

Eighty-three of our series were pneumonectomies and 67 were lobectomies or resections of units smaller than a lobe. Two of the group underwent a second resection giving a patient total of 148. The mean age of our patients was 28. The extremes were 20 and 56. There were 96 white and 52 Negro patients.

The racial distribution is of interest in that of the 52 Negroes who underwent resection 36, or 69 per cent, had pneumonectomy. This is in accord with the analysis of data presented at the Fourteenth Chemotherapy Conference[3] where it was shown that Negroes coming to surgery often require more extensive resections than white patients.

Streptomycin was the only antimicrobial drug used during the period covered by this series. Ninety-seven per cent of our patients received streptomycin during the pre- or postoperative period, or during both. One hundred and one of these were original treatment and 45 were re-treatment patients. The majority were given the drug for one week before and two weeks after operation, as was the custom at that time. Sensitivity studies were not available in sufficient numbers to be significant.

Eighty-five per cent of the pneumonectomy group and 58 per cent of the lobectomy patients were classified as far advanced. Ninety-one per cent had positive sputum during the immediate preoperative period. The high

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Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

percentage of positive sputum patients in this series is in marked contrast to the present day experience. At the Fourteenth Chemotherapy Conference[3] only 43 per cent of 1,133 patients, who had a resection during the previous year, were positive at the time of surgery. Forty of the patients in this study, or 27 per cent, were found to have positive smears or cultures at some time during the postoperative period of hospitalization. The conversion rate was higher in the pneumonectomies (77 per cent) than in the lobectomies (67 per cent), and preoperative thoracoplasty in the latter group did not apparently influence sputum conversion. Eighty five per cent of the entire group had open lesions and all but 9 of these were sputum positive.

Thoracoplasty failure was the indication most commonly found, followed by destroyed lung, and pneumothorax failure. Thoracoplasty was performed in 41 per cent of our cases preoperatively, and 42 per cent postoperatively. No concomitant thoracoplasties were done.

Bronchopleural fistula occurred after 15 per cent of the subtotal resections and 26 per cent of the pneumonectomies. Chest wall sinus, early spread, wound infection, and delayed re-expansion followed in order of frequency (Table I). While the occurrence of a bronchopleural fistula must be regarded as a most serious complication, it was heartening to learn that many of these patients were salvaged. Thirty two of our patients developed such a complication and when our study was concluded it was found that 44 per cent of these were at home with inactive disease. Empyema without fistula was encountered only three times. It should be noted that with the passage of time the number of patients who developed fistulas has increased. The rate found in the present survey was 21 as compared to 15 per cent which was reported in an earlier study of the same patients. Forty six per cent of the entire group of resections were followed by complications, and a greater incidence was noted in our white patients.

TABLE I. COMPLICATIONS

	LOBECTOMY SEGMENTAL		PNEUMONECTOMY		TOTAL	
	NO.	%	NO.	%	NO.	%
Bronchopleural fistula without empyema	10	14.9	22	26.0	32	21.3
Emypema without bronchopleural fistula	0	0	3	3.6	3	2.0
Chest wall sinus	4	5.9	13	15.7	17	11.3
Early spread	3	4.5	10	12.0	13	8.6
Wound infection	6	8.9	7	8.4	13	8.6
Delayed expansion or apical space	8	11.9	0	0	8	5.3
Others	14	20.0	23	27.7	37	24.6

Eighteen patients (Table II) died in the hospital without an intervening discharge and 8 died following discharge. The surgical mortality was thus 9 per cent while the total rate was 17 per cent. The rate was higher in the pneumonectomy group than in those patients who had a lobectomy or a segmental resection. Three of the four operative deaths were due directly to hemorrhage and one to cardiac arrest which occurred in the early stage of a secondary resection. The fourteen postoperative deaths were due mainly to bronchopleural fistula or the sequelae thereof, pneumonitis, spread, cerebrovascular accident, tuberculous meningitis, and other various causes. The eight nonsurgical deaths resulted from malignancies, heart disease, diabetes, accidents, and other causes not related to the surgery.

TABLE II. MORTALITY DATA

	NUMBER OF OPERATIONS	SURGICAL				NONSURGICAL		TOTAL	
		OPERATIVE		POSTOPERATIVE					
		NO.	%	NO.	%	NO.	%	NO.	%
Lobectomy—segmental	67	2	3.0	4	6.0	3	4.5	9	13.5
Pneumonectomy	83	2	2.4	10	12.0	5	6.0	17	20.4
Total	150	4	2.7	14	9.3	8	5.3	26	17.3

Follow-up information was obtained from results of recent check-ups at Oteen or other VA Hospitals and Regional Offices, or from completed forms which were sent to all of the patients in the series who could not be accounted for by the former method. We have been able to obtain data on all of the 130 patients discharged from the hospital alive, giving 100 per cent follow-up.

The follow-up data are recorded on Table III. The "Excellent" category includes those who are at home with inactive disease, have essentially no symptoms, and are working. One must meet the same requirements to qualify for the "Good" group except that these patients are not working. A "Fair" result was used to include those who are home carrying out reasonably normal lives but with active disease or partially disabling symptoms and those who are in the hospital but without evidence of active disease. The "Poor" result patients are still hospitalized with active disease. There is some question as to the advisability of separating the nonworking from the working group since many of those classified as "Good" were discharged from our rehabilitation division with an eight-hour work tolerance. For this reason, we believe that these two groups should be combined. By doing so, we find that 107 patients, or 72 per cent, of the original group of 148 patients are classified as satisfactory. The 15 patients in the fair and poor groups, as well as the 26 who died, regardless of cause of death, are considered as unsatisfactory. No significant difference was noted in the percentage of satisfactory results when studied on the basis of race.

TABLE III. FOLLOW-UP DATA

	LOBECTOMY SEGMENTAL		PNEUMONECTOMY		TOTAL	
	NO.	%	NO.	%	NO.	%
Excellent	27	41.5	42	50.5	69	46.6
Good	23	35.4	15	18.1	38	25.7
Fair	2	3.1	8	9.7	10	6.8
Poor	4	6.2	1	1.2	5	3.4
Dead	9	13.8	17	20.5	26	17.5
Total	65	100.0	83	100.0	148	100.0

Late reactivation has been a disturbing feature of this follow-up study. This problem was emphasized by Sweet[4] in his report of cases treated by resection during the pre-streptomycin period. An over-all total of 25 patients, or 17 per cent, developed a late reactivation. Twelve of these recovered, 7 on medical therapy and 5 after secondary resections. Eleven treated medically remain active, one patient died of his disease and another following a second resection.

DISCUSSION

This series of resections was accomplished during the years immediately following the introduction of streptomycin. Judged by present standards of chemotherapy, the duration of treatment was inadequate. A large percentage of the patients had far-advanced disease, open lesions with positive sputum, and were failures of other means of therapy. Many would fall in the category of salvage cases. Even so, we find that 72 per cent of 148 patients who underwent a resection, and 82 per cent of those who were discharged from the hospital alive are at home with inactive disease.

Developments in the field of chemotherapy since 1950 have been dramatic. The addition of new drugs and improved methods of application of the older ones have resulted in such a decrease in the size of the lesions and extent of resection necessary for their removal that it is impossible to compare surgery as done at the present time with the early series, or to make a prediction of results to be expected from such surgery. Drug resistance is still another important factor to be considered. It is felt, however, that data reported in this study are of value as a record of results achieved by resection during the pioneer days of streptomycin therapy.

SUMMARY

1. A series of 150 resections for pulmonary tuberculosis done between October, 1946, and April, 1950, is reported. Eighty-three of these were pneumonectomies and 67 were lobectomies or resections of smaller units than a lobe.
2. The operative mortality was 2.7 per cent and the total mortality was 17.3 per cent.
3. Our study includes 100 per cent follow-up.
4. Seventy-two per cent of the entire group, and 82 per cent of the patients who left the hospital alive have obtained satisfactory results.
5. Negroes often required a more extensive resection than white patients but did as well or better insofar as mortality, morbidity, and long-term follow-up were concerned.

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DISCUSSION

PROFESSOR J. F. NUBOER, Utrecht, Holland.—First of all, I want to thank you very much for the invitation to attend this meeting. It is an excellent one indeed.

I should like to say a few words in discussion of the paper of Dr. Davis, which I appreciated very much. I congratulate him on his excellent results.

As you perhaps know, tuberculosis in Holland increased greatly after the war. Now the disease is under control again, the mortality rate for 1955 being 6.6 per 100,000. Our policy with regard to the treatment of tuberculosis differs somewhat from that in your country. About 30 per cent of our sanatorium patients are operated on, about the same percentage as here. However, before the operation we give as little streptomycin as possible. In every case where the possibility of an operation is foreseen, streptomycin is given in the preoperative phase only under special indications, for example, in case of hematogenous spread or tuberculous bronchitis or extensive disease which is not possible to control by medical treatment alone.

Para-aminosalicylic acid (PAS) treatment in the Dutch sanatoriums is a very rigorous regimen. During the preoperative phase, the patient gets in addition, para-aminosalicylic acid and isonicotinic acid hydrazide (INH). After the operation, streptomycin is given for about three months during the aftertreatment in the sanatorium, which lasts for at least six to eight months.

Resection therapy for lung tuberculosis was started in Holland in 1946. In the beginning, we had no streptomycin or other antituberculosis drugs. The results were disappointing at first, but as soon as we could use streptomycin there was much improvement.

(slide) Until the first of March, 1956, in the surgical department of Utrecht University Hospital, 1,173 lung resections were performed, 1,161 under cover of streptomycin and other drugs.

(slide) The first 12 patients were operated on without streptomycin; the mortality was 25 per cent. In the other 1,161 operated on under cover of streptomycin, PAS, and INH, the mortality was 1.63 per cent. For the entire series, the mortality was 1.87 per cent. In 6.6 per cent of the cases, we saw spread or reactivation; most of the cases were cured by different means.

The late mortality in the series was 1.9 per cent. Some died of cancer, some as a result of accidents, several as the result of the original disease. Because practically always reactivation and spread were seen during the first months after operation, we are convinced that the three- to ten-year results can be evaluated just as the five- to ten-year results. Our follow-up is 100 per cent, which is possible in a small and densely populated country like Holland.

(slide) In the series of patients operated on five to ten years ago, 98.5 per cent of the surviving and 85.7 per cent of the total group have negative sputum on culture, and are working or able to work.

(slide) The results in the group operated on three to ten years ago are about the same, 97.5 per cent of the surviving and 90.5 per cent of the total having negative sputum on culture.

In Holland, we are rather satisfied with the results of resection therapy in lung tuberculosis.

DR. JOHN MAXWELL CHAMBERLAIN, New York, N. Y.—Before this Association, during the last nine years, we have reported on our results in segmental resection. First, we reported on the first 100 cases, later on 200 cases and, finally, three years ago on the follow-up of 300 cases followed for two to five years. In view of the fact that our first segmental resection was done in 1947, we do not have a ten-year follow-up such as that of Dr. Murphy and Dr. Davis, but we do have a five- to nine-year follow-up on 150 cases, and Dr. Klopstock has just sent me in a letter the last word on the first 161 cases on which we performed segmental resection between 1947 and 1953.

There are now 135 of the 150 we were able to follow; 135 classified as living and well, with negative cultures, negative x-rays, and working or capable of working. Six patients are living with disease. I believe our percentage would be 90 per cent living and well; 3 per cent living with disease; and 10 patients or 7 per cent dead. Of the 10 who died, 4 died of tuberculosis and 6 died of unrelated causes.

I realize that this is only one aspect of the surgical treatment of this disease, but the figures seem to be quite good and I suppose that means, in comparison with the figures you have just seen in which the patients had so far advanced disease that it was necessary to do pneumonectomy or lobectomy, that these patients convinced us that the earlier you can treat the disease surgically the better will be our long follow up results.

DR. JOSEPH W. GALE, Madison, Wis.—I thought it might be interesting at this time to refer to a group of patients, some of whom were operated upon before the era of antimicrobial therapy. We reported 80 patients in 1949 who had been operated upon and only about one third of whom had the advantage of streptomycin treatment.

(slide) Our results are different from those of the essayist in the early cases. I think this is probably because we were working on the burned out cases, since we had very few patients with acute disease in the bronchi. This group includes 1,165 cases who have been followed over a period of one to ten years. You will note the predominance of far-advanced cases in this group. The minimal is the smaller group. We have been told that we do not have much tuberculosis in Wisconsin and that most of it is minimal. I believe these figures prove differently.

(slide) Our chief complication following surgery, however, in spite of the fact that we have tried to check the bronchi carefully, has been bronchopleural fistula. Our figures show that 20.5 per cent of the cases developing fistula died of sepsis or some other type of infection.

(slide) The total operative deaths in this group: following pneumonectomy, 21; following lobectomy, 13; following segmentals, 2—both accidental, but nevertheless they died and we have to figure they are an operative mortality. We had 36 operative deaths in this group of 1,165.

(slide) These are the nonoperative deaths which occurred over ninety days after the patient was discharged from the hospital and were not involved with the surgery in any way whatsoever. They exceeded the operative deaths by three.

(slide) So, in summary, we have 1,167 cases, operative deaths, 36; nonoperative deaths, 39. Fifty of these patients have not been followed recently enough to be included. It takes considerable time to follow patients over a ten year period when you get into figures above 1,000.

DR. MURPHY (Closing).—I merely wish to restate the fact, which Dr. Davis emphasized, that it is impossible to compare results in those early days with present-day results. At that time, you will remember, we thought that streptomycin was going to be simply an adjunct to surgery. It now appears that the process has been reversed, and that surgery is, by and large, an adjunct to the chemotherapy of tuberculosis. The results we obtained at Oteen, while not quite as good as those quoted by the various discussants, indicate we believe that resection for tuberculosis is a good method of treatment and is here to stay.

THE ROLE OF CHRONIC OCCULT POSTRESECTION FISTULAS IN THE REACTIVATION OF TUBERCULOSIS: PATHOGENESIS AND TREATMENT

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(BY INVITATION)
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IN CONSIDERING the etiology of tuberculous reactivation following pulmonary resection, little attention has been given to the possible association of chronic occult bronchial fistulas. With reports of resection for pulmonary tuberculosis ever increasing, we believe this important postoperative phenomenon should be given additional emphasis and amplification as a definite clinicopathologic entity.

In a recent paper, Franz and Murphy[1] described 4 cases of masked bronchial fistulas. Only one of these patients, however, had evidence of persistent tuberculous activity. We prefer the term "occult," rather than masked, as suggested by Murphy. While the average postoperative bronchopleural fistula is overt in its manifestations, the occult fistula is characteristically silent. Following surgery, such a fistula may be present for a period of two years or longer (Fig. 1), while the patient remains completely asymptomatic.

MATERIAL

A study of 8 patients, with postresection tuberculous infection of the operative site, forms the basis of this report. Because the clinical pattern, type of primary and secondary operation, pathologic and bacteriologic findings were similar for the entire group, they will not be described individually.

At the time of the original resection, the patients were being treated with drug combinations, consisting of two major drugs in 4, and three major drugs for the other 4 (Table I). A re-treatment program had been advised in 7 cases to achieve sputum conversion, in spite of persistent cavitary disease. One patient arrived at the open negative state as a result of original chemotherapy. Four of the remaining 7 patients were sputum negative prior to surgery as the result of a re-treatment drug regimen. One patient had received thirty months of chemotherapy and had ancillary collapse measures of both pneumoperitoneum and pneumothorax before resection was contemplated. The reappearance of a left upper lobe cavity, following abandonment of the pneumothorax, led to a recommendation for pulmonary resection.

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Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

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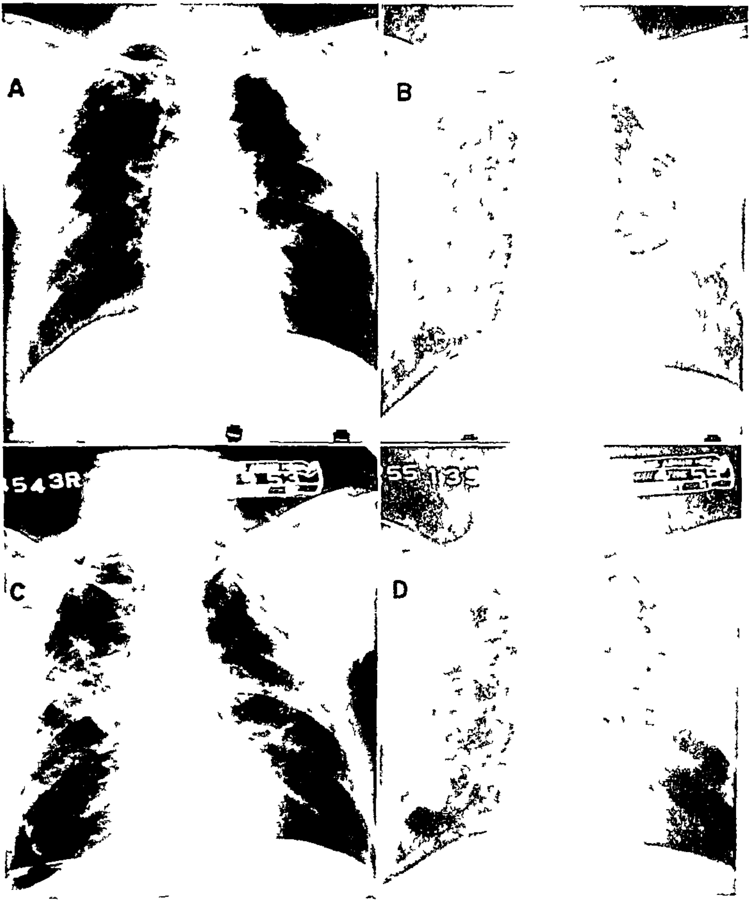


Fig 1.—*A* Preoperative 2 cm cavity posterior segment right upper lobe

B, Preresection thoracoplasty right

C Nine days postresection (apical and posterior segments) showing persistence of local pneumothorax

D Two years after bisegmental resection Pneumothorax pocket in exactly same area as immediately postoperatively sputum continuously positive

TABLE I. CHRONIC OCCULT FISTULAS
DATA PRIOR TO RESECTION—8 PATIENTS

CHEMOTHERAPY				
COURSE		MAJOR DRUGS		DURATION
Original treatment	1	SM,* PAS†	3	Four to 30 months
		INH‡ added between resections	2	
Re-treatment	7	SM, INH	1	
		Viomycin added between resections		
		SM, PAS, INH	4	
		Viomycin added between resections		

*SM—streptomycin.
†PAS—para-aminosalicylic acid.
‡INH—isonicotinic acid hydrazide.

Only one of the group had tubercle bacilli completely susceptible to both drugs in the last preoperative or preconversion sputum (Table II). The significance of organisms resistant to one or more drugs in the sputum of the remaining 7 patients was not appreciated at this time. A cavitary lesion was present in the upper lobe of 7 patients at the time of surgery, while in one patient a pre-existing cavity had closed some two months before resection.

TABLE II. CHRONIC OCCULT FISTULAS
DATA PRIOR TO RESECTION—8 PATIENTS

BACILLARY RESISTANCE IN PREOP. SPUTUM		SPUTUM STATE AT OPERATION		STATUS OF LESION	
Susceptible	1	Negative	5	Cavitary	7
One drug	3	Positive	3	Noncavitary	1
Two drugs	2				
Three drugs	2				

In every resection performed in this group, an effort was made to excise all palpable disease in the unilateral lung. This was accomplished, with the exception of fine 2 to 3 mm. scattered seeding, by primary resections ranging from multiple wedges up to a maximum of two segments (Table III).

TABLE III. CHRONIC OCCULT FISTULAS
POSTRESECTION TUBERCULOUS REACTIVATION—8 PATIENTS

TYPE PRIMARY RESECTION		BACILLARY RESISTANCE IN SPECIMEN		TUBERCULOUS REACTIVATION POSTOPERATION
One segment	2	Susceptible	1	Three weeks to 3 months
Two segments	4	One drug	1	
Multiple wedges	2	Two drugs	3	
		Three drugs	3	

At the time of resection, in each instance there was no gross spillage of caseous material, and it was believed that the tuberculous lesions had been completely encompassed. There *was no macroscopic evidence of endobronchial disease* in any case, either by *preoperative bronchoscopy or observation at the time of bronchial transection.*

In each patient, tubercle bacilli were recovered by culture from the resected material (see Table III). Again, in only one specimen were the organisms susceptible to the drugs being administered It is important, and this was realized only in retrospect, that equivalent or *greater* resistance was found in the organisms recovered from tissues than was present in the preoperative sputum cultures Moreover, half of this group had negative sputum for three to five months prior to their first resection (see Table II)

DIAGNOSIS AND CLINICAL SYNDROME

The absence of any subjective symptoms, directly attributable to a post resection fistula, increases the difficulty of diagnosis One of our patients failed to gain weight postoperatively, in spite of nutritional supplements The remaining 7 were completely asymptomatic

The ordinary congestive changes in the lung resulting from the trauma of wedge or segmental resection usually resolve in varying degree during the first postoperative month Persistence of a hazy density beyond this period suggests more than an operative defect (Fig 2) The development of a semi annular shadow, usually without an air fluid level may indicate an occult fistula (Figs 2 5) The respective contribution of parenchymal induration or pleural fluid to the density increases the difficulty of radiologic interpretation

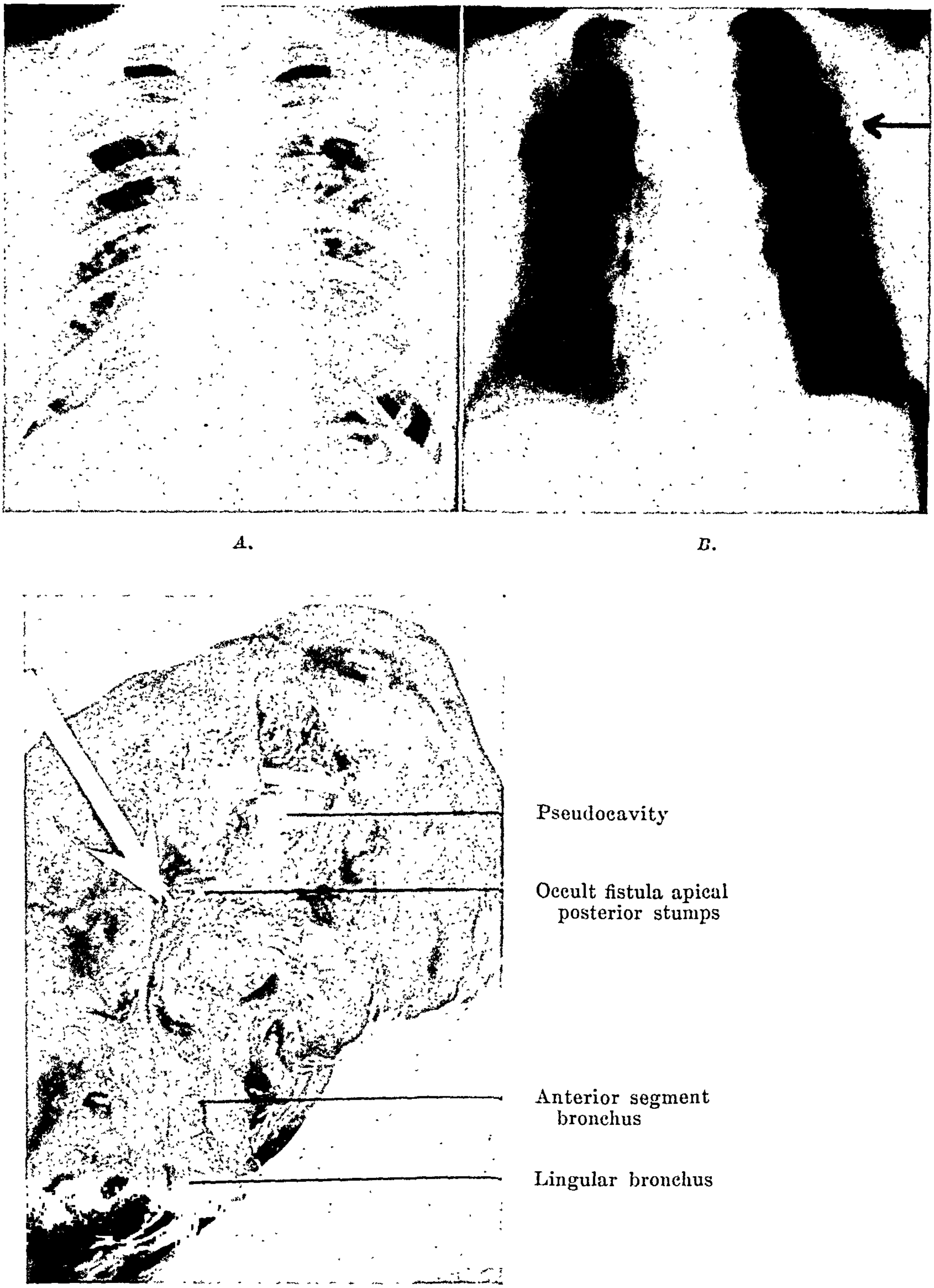
The fact that a pseudocavity may be bounded on all sides by parenchyma or on the third side with parietal chest wall, makes the use of planigrams almost mandatory for the recognition of these defects Body section planigraphy, at the level of the segmental stump (see Figs 2, 4 5) may reveal a pyramidal or annular radiolucency This configuration can easily be ignored on the routine posterior anterior chest film

A further diagnostic aid in the demonstration of an occult fistula and parafistulous space is bronchoscopy and bronchography Bronchoscopic inspection of the segmental stump may reveal several black silk sutures embedded in gray, edematous granulation tissue, rather than a well healed stump Instillation of radiopaque media may show partial filling of the parafistulous cavity, with clubbing or a blob of oil just distal to the level of segmental stump transection (Figs 5, 6)

Tuberculous reactivation almost invariably was suspected radiologically before bacilli reappeared in the sputum This situation, of course, pertains only to those patients operated upon while in the sputum negative state Bacteriologic relapse in the presence of serial x ray evidence of slowly resolving infiltration, at or near the resection site, leaves little doubt of tuberculous reactivation

In this group of reactivations, associated with occult fistulas, both x ray and bacteriologic evidence was confirmatory by the third postoperative month (see Table III)

While not so dramatic as the postoperative reappearance of bacilli seen in the open negative patients, the failure of a resection to alter a preoperative positive sputum may be sufficient evidence to suspect a tuberculous infection in the operative site, particularly if the contralateral lung is free of active disease


Pseudocavity
Occult fistula apical posterior stumps
Anterior segment bronchus
Lingular bronchus

A. *B.*

C.

Fig. 2.—*A*, Two months after resection of apicoposterior segments. Patchy infiltration persists in left upper lobe.

B, Planigram showing semi-annular shadow at resection site.

C, Gross specimen, left upper lobe, from secondary resection. Pseudocavity (4 cm. in diameter) lined with necrotic tuberculous granulation. Arrow indicates occult fistulas of segmental stumps.

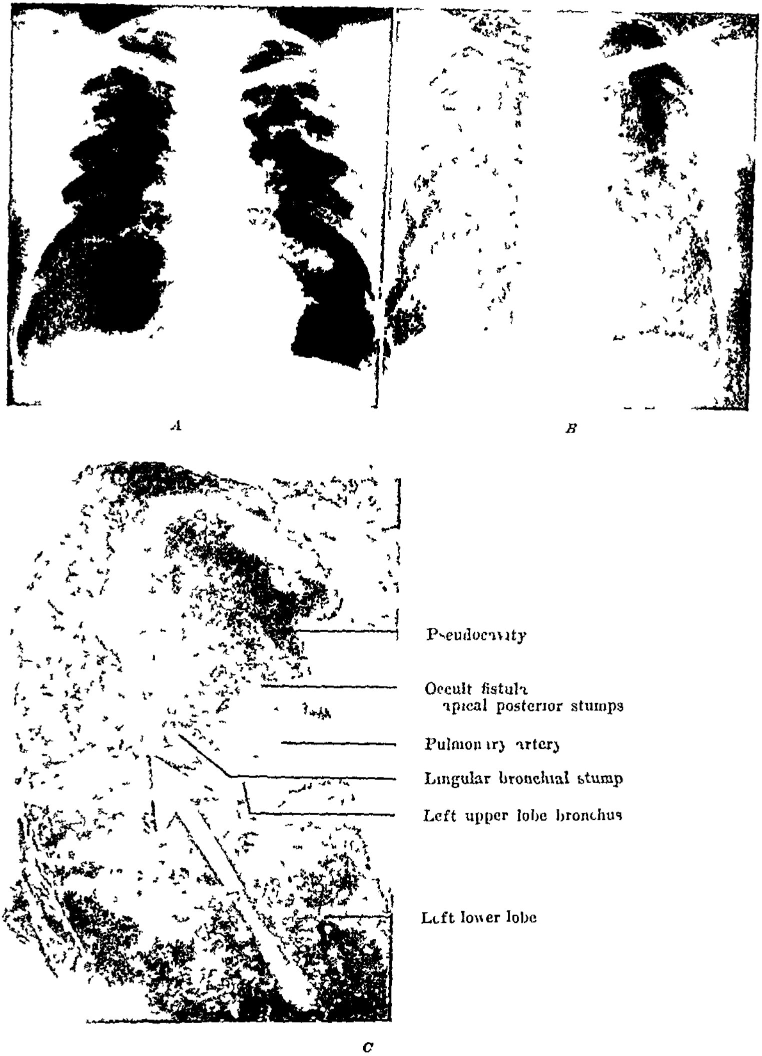


Fig. [illegible]—A. Preoperative x-ray revealing twin cavities in left upper lobe.

B, One month following apicoposterior segment resection Semi annular pneumothorax per[illegible] [illegible] of resection

C, [illegible] specimen left upper lobe from post mortem. Pseudocavity (6 cm in diameter) full of blood clot and lined with tuberculous tissue Arrow indicates occult fistula and site of erosion into pulmonary vein causing fatal hemorrhage

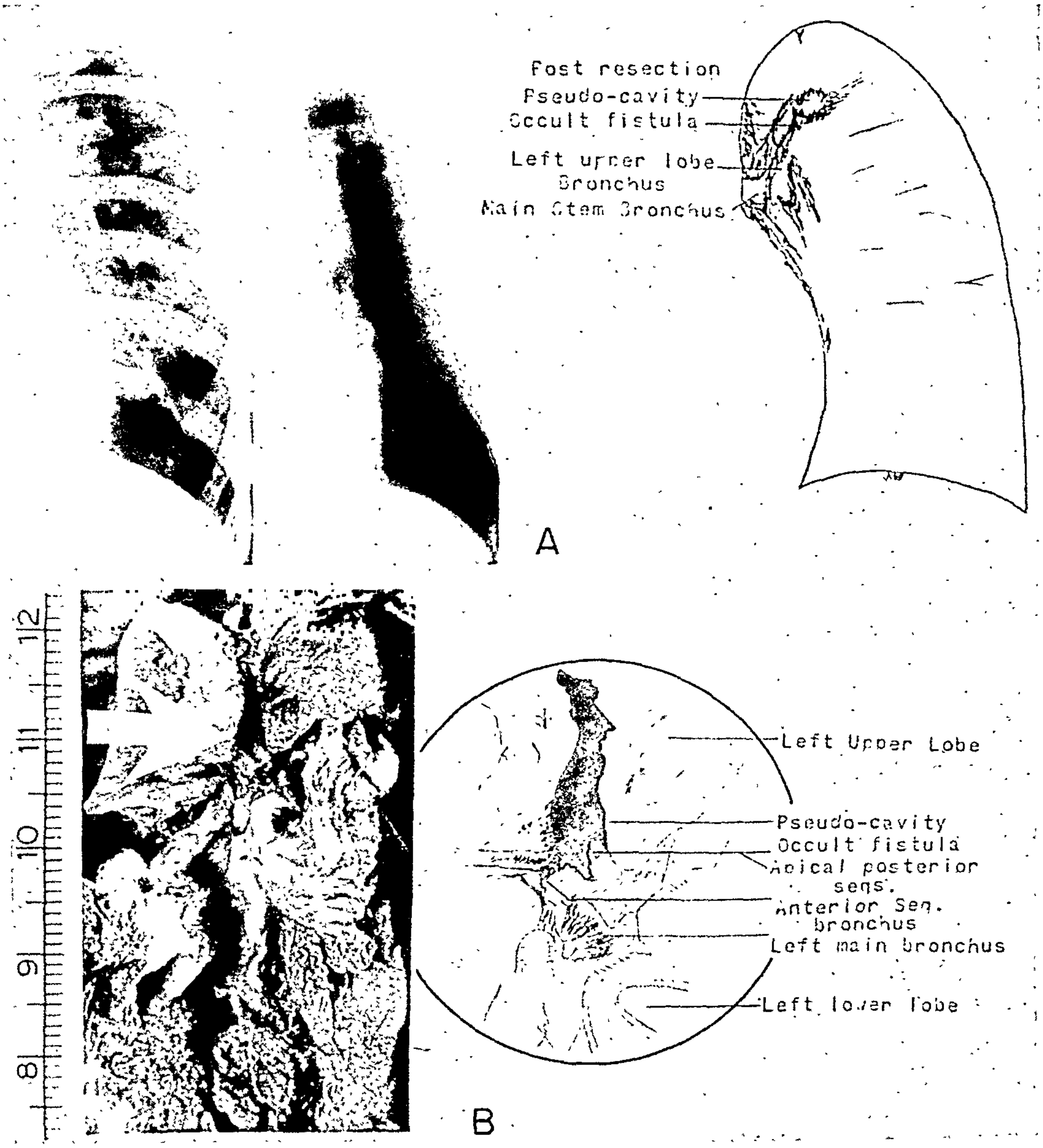


Fig. 4.—*A*, X-ray, planigram and diagram, six months after operation, showing small (2 cm.) cavity at site of apicoposterior segment resection.

B, Gross specimen, left upper lobe, removed at secondary resection. Arrow and diagram indicate 2 cm. postresection defect and occult segmental fistulous stumps.

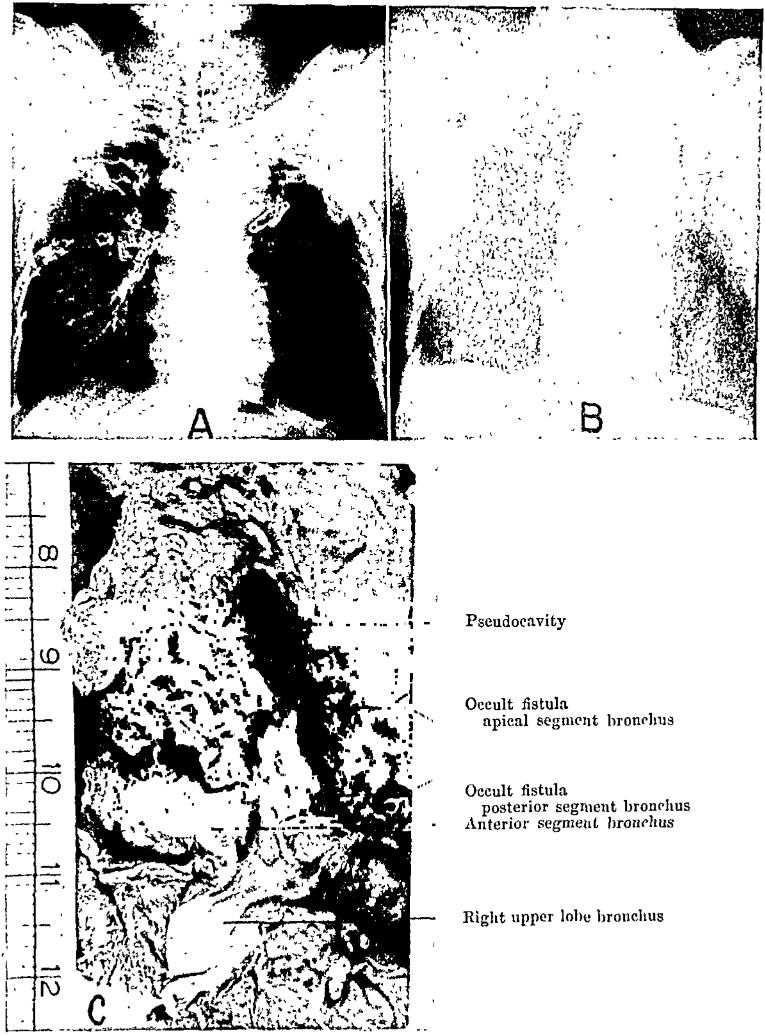

A
B
8
9
10
11
12
C
Pseudocavity
Occult fistula
apical segment bronchus
Occult fistula
posterior segment bronchus
Anterior segment bronchus
Right upper lobe bronchus

Fig. 5.—*A*, Bronchogram, six months after resection of apicoposterior segments, right upper lobe, revealing puddling of oil just distal to segmental fistulous stumps.

B, Planigram, six months postoperation, showing annular shadow with air bronchogram of segmental bronchial stumps at apex of defect.

C, Gross specimen. Remainder of right upper lobe removed at secondary resection. Pseudocavity, with many black silk sutures, in wall connecting directly with infected fistulous tract.

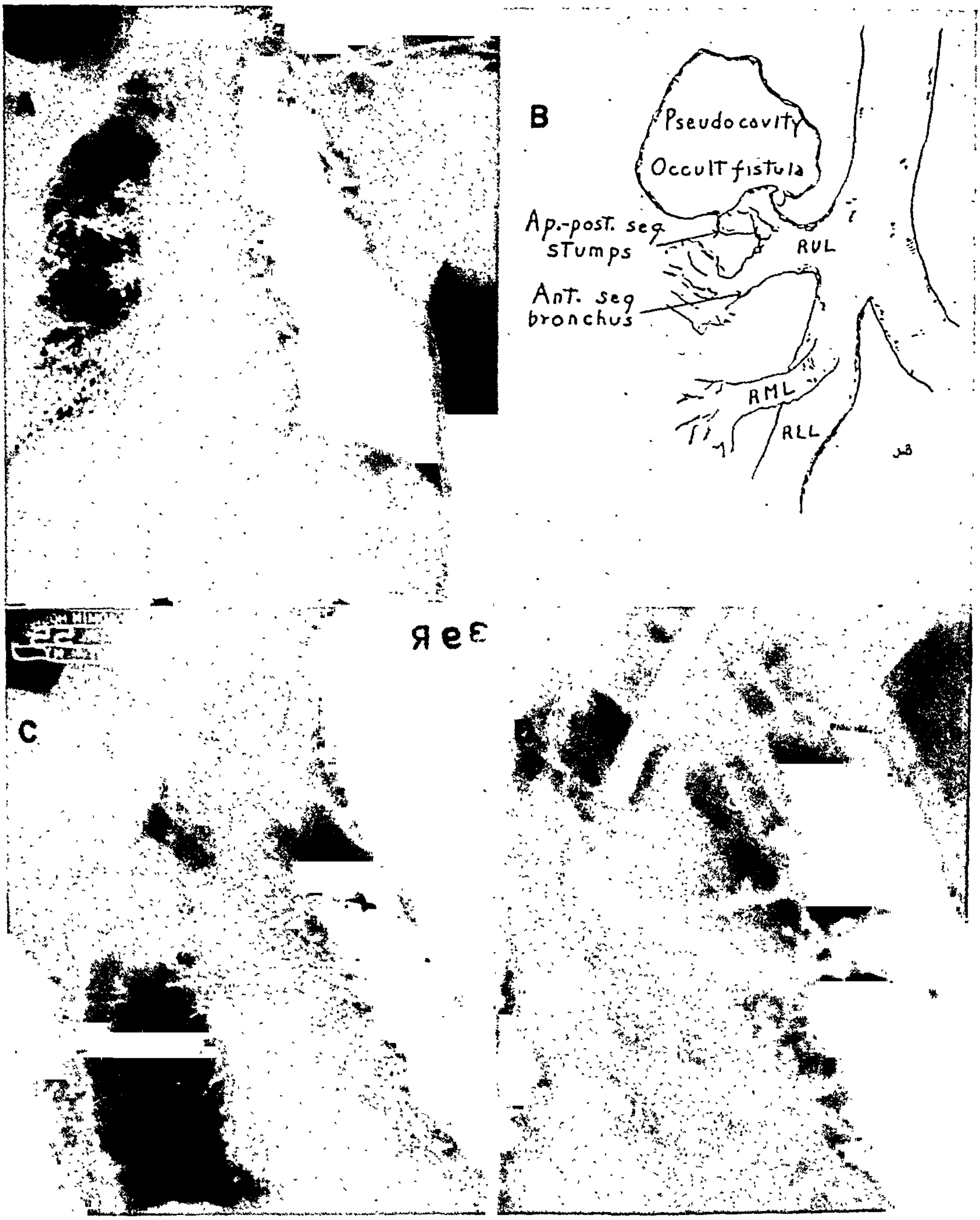


Fig. 6.—*A*, Bronchogram, two years after bisegmental resection, outlining configuration of pseudocavity.

B, Diagram showing semi-annular shadow with occult fistulas at apex.

C, Oblique bronchogram.

D, Spot bronchogram revealing detail of puddling at segmental fistulous stumps and filling of anterior segment bronchus.

PATHOGENESIS

In our experience, the postresection phenomena of a chronic tuberculous fistula and a parafistulous space are due to two factors mechanical and infectious The lung adjacent to the wedge shaped defect resulting from a segmental excision must expand and undergo readjustment during the immediate postoperative period The manner in which this takes place depends a great deal on the relation of the operative area to the chest wall, on the expandibility of adjacent parenchyma and the measures which the surgeon takes to aid nature's reconstitution of the lung

A space remaining at or near the operative site may fill with blood or serofibrinous exudate This fluid may be an ideal culture medium for a local tuberculous empyema As (drug resistant) bacilli flourish, the segmental bronchial stump, originally adequately closed by sutures, can break down

Once bronchial communication has been established, and the liquid contents sloughed, the morphology and behavior of the new cavity is quite similar to a typical tuberculous cavity Designated a pseudocavity because one of the boundaries *may* be parietal pleura rather than completely enclosed by lung, this infected space may be larger than the cavity for which the primary resection was performed (Fig 7)

Macroscopic Findings—Gross examination of these infected operative sites reveals a rather uniform appearance (Figs 2 5, 7, and 9A) The inner surface is granular, irregular, and lined for most of its extent by grayish red necrotic tissue The bronchial stumps are dirty and unhealed Black silk sutures scattered about the inner wall are a common finding in most of the specimens There may or may not be a well delineated wall between the infected pseudocavity and the adjacent lung tissue

Microscopic Findings—A common finding in six of the eight secondary specimens (seven obtained at secondary resection and one at post-mortem) was a cavity wall lined with necrotic material of variable thickness In some regions, this necrotic zone was extremely wide and within it the former structure of the lung parenchyma may still be discernible Beyond the necrotic tissue there was a zone of scar tissue which varied considerably in thickness and cellularity in different areas, but this zone of fibrous tissue appears to be continuous between the necrotic tissue and the adjacent lung parenchyma This finding indicates that the tuberculous disease in the lung can hardly have arisen by a penetration of the infection into the lung substance

The major factor in the etiology and dissemination of tuberculosis in these patients is found in the nature of the fistulous tract Those specimens of particular interest which contribute to an understanding of the pathogenesis will be described briefly, but in detail

CASE REPORTS

CASE 1—(Fig 2) Sections through the fistulous tract (Fig 8, *A*) that is connected with the upper lobe bronchus show almost the entire surface to be necrotic tissue that is quite heavily infiltrated with neutrophils Beyond this necrotic layer, there is a well formed scar which separates the tract from the surrounding tissue The larger bronchial

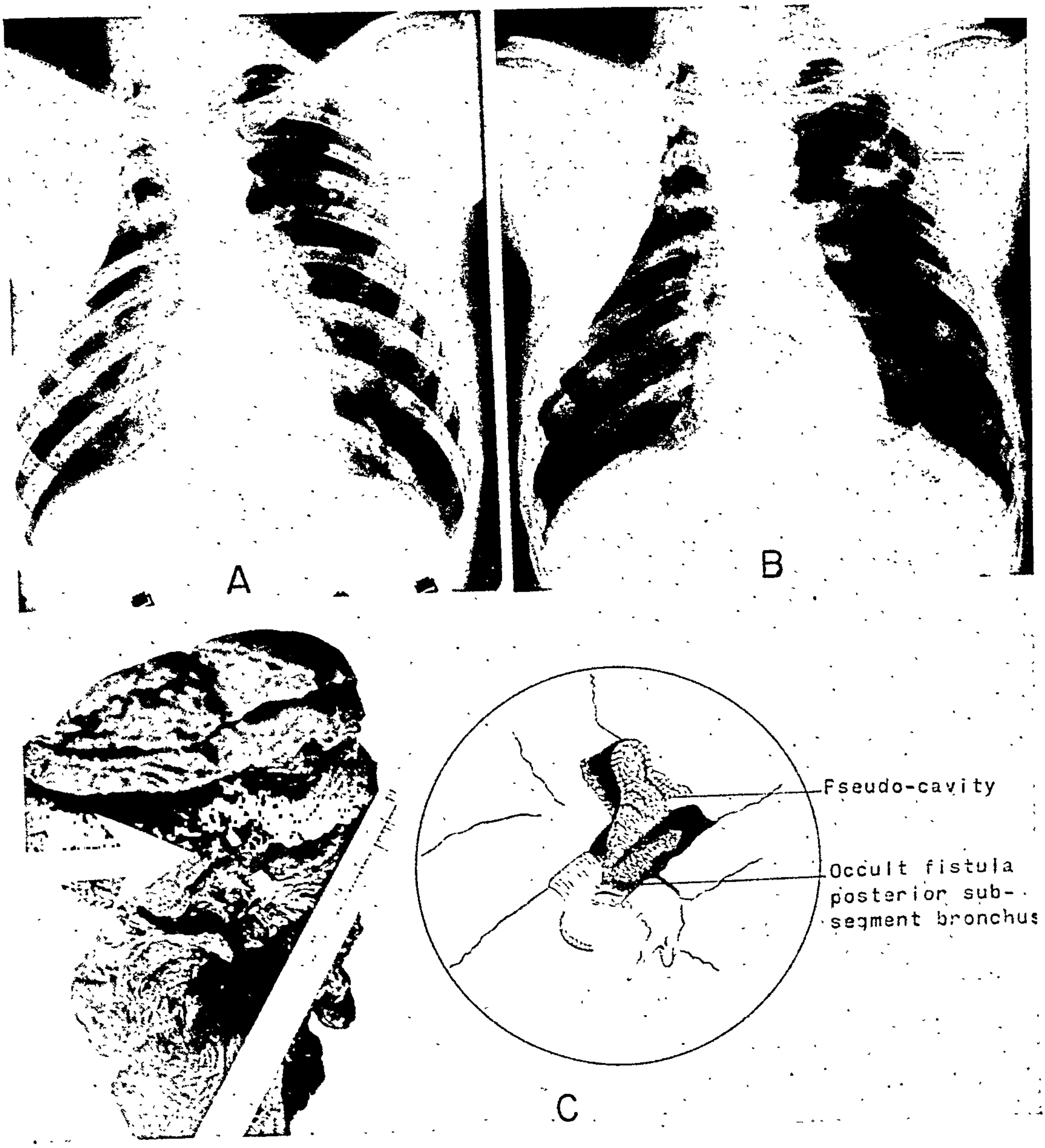


Fig. 7.—*A*, Two centimeter cavity in posterior segment, left upper lobe, preoperatively. *B*, Three centimeter pseudocavity, at site of wedge resection, four months after operation. *C*, Gross specimen, superior division, left upper lobe, removed at secondary resection, showing 3 cm. infected operative site and occult tuberculous fistula.

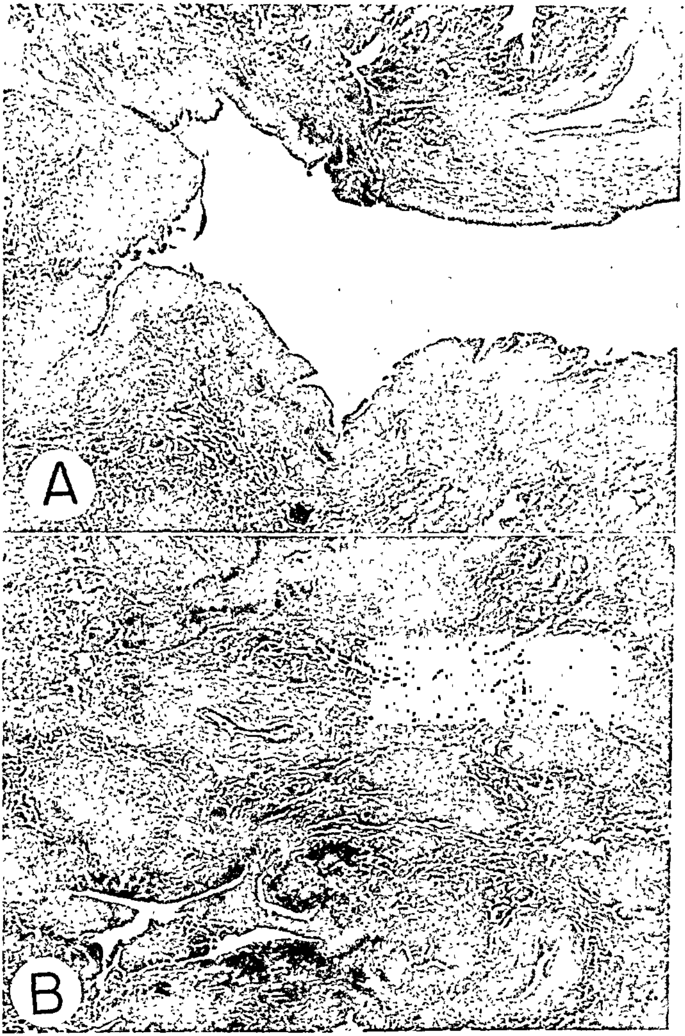


Fig. 8.—*A*, Photomicrograph (×15; reduced ⅙). "Occult fistulous tract"—the entire inner surface is necrotic and heavily infiltrated with neutrophils. Beyond necrotic zone, there is a zone of scar tissue, separating the tract from surrounding tissues.

B, Photomicrograph (×15; reduced ⅙). Section of lung adjacent to fistulous tract. Many foci of tuberculous pneumonia. Fresh lesions, both necrotic and non-necrotic, from bronchial dissemination. Large bronchus in lower left quadrant contains necrotic debris and shows necrosis of bronchial wall in these areas.

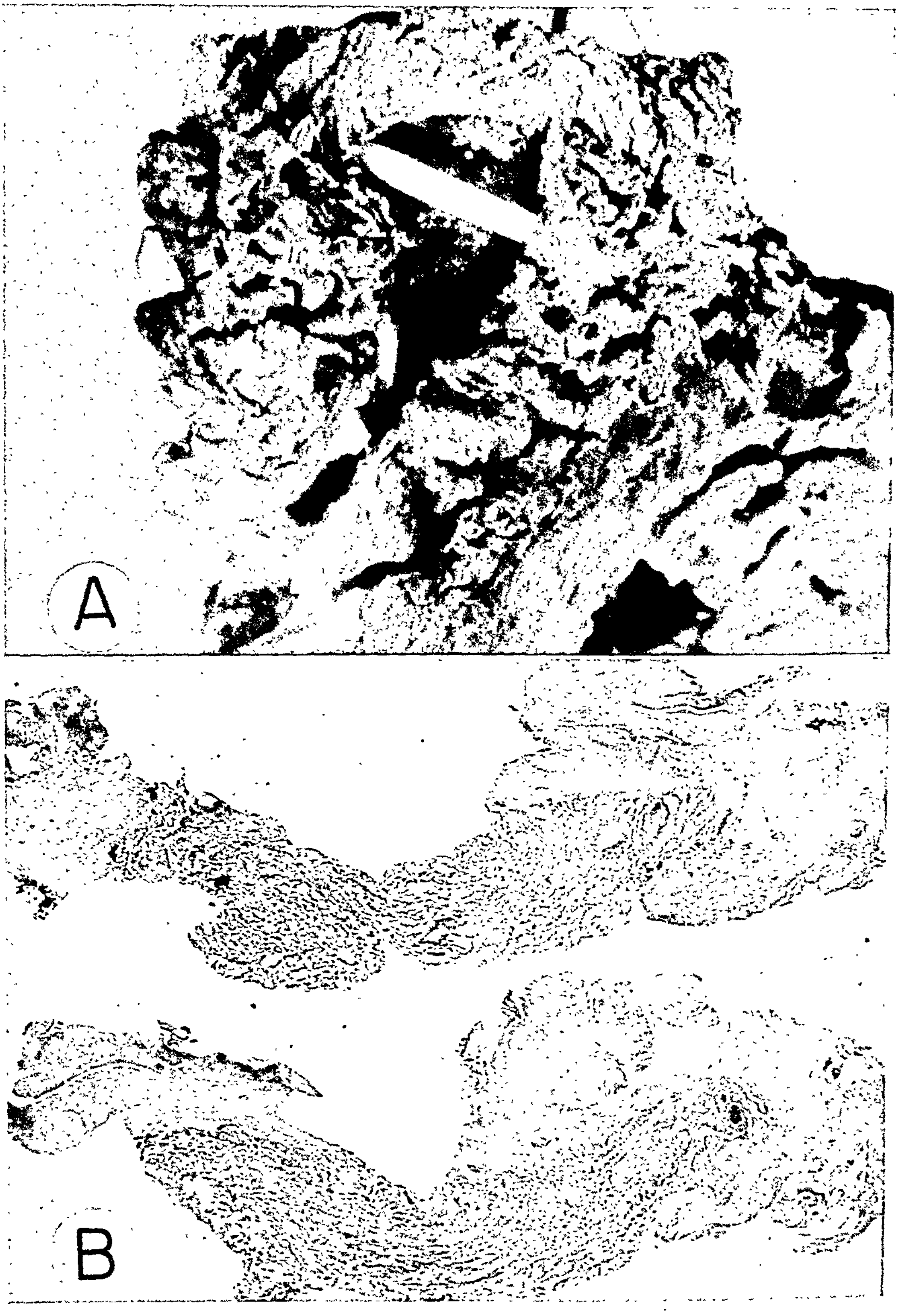


Fig. 9.—*A*, Gross specimen, remainder of right upper lobe (same case as Figs. 1, 6) revealing occult fistulous tract leading directly to pseudocavity at segmental resection site.

B, Photomicrograph (×15; reduced ⅙) through tuberculous fistulous tract, with the surface necrotic in sizable areas. Two sutures are seen and around both there is necrotic tissue.

structures in the hilar region show no *evidence* of necrotic endobronchial tuberculosis, but all show considerable lymphocytic infiltration of the mucosa

There are several *foci of* suture material in the tissue adjacent to the sinus tract Most of these show no inflammatory reaction, and *are* surrounded by scar tissue However, in this hilar portion two sutures have *tuberculous* lesions with necrosis about them This situation suggests that there had been an *implanted tuberculous* infection at the time of the previous surgery

CASE 2—(Figs 1, 6, 9) Sections *through the fistulous* tract (Fig 9, *B*) show considerable scar tissue, with the surface being necrotic in sizable areas In this portion, there are two sutures, and around both *there* is necrotic tissue No evidence of tuberculous infection of the larger bronchial branches in the hilar *region* is found

Summary of Pathology—It appears that, in this group of seven specimens (secondary resections) the *tuberculous* involvement is related to an *implantation infection* at the time of *the primary* resection, rather than to a necrotic endobronchial tuberculosis that was *present* at the time of surgery The presence of suture [illegible] *directly involved* in the necrotic tuberculous disease, is additional [illegible] *to suggest that* implantation infection had occurred at the time [illegible] peration

In fou[illegible] [illegible]cimens, recent foci of lobular pneumonia were found in the par[illegible]nt to the fistula *(Fig 8, B)* In several lesions, bronchi, in due [illegible] with *these* areas, contained necrotic debris These lesions [illegible] the result of endobronchial dissemination from the sinus trac[illegible] [illegible]ded that the surgeons *removed* all palpable disease in the [illegible] it is probable that *all of the recent tuberculous disease in these specimens* [illegible]*ted from endobronchial dissemination from and subsequent to the* [illegible] *f the tuberculous fistulous space*

DISCUSSION

Stemmermann Daniels, and Auerbach[2] have studied the pathogenesis of bro[illegible]hopleural fistulas following *excisional therapy for pulmonary* tuberculosis They mention 9 cases of postoperative fistulas, 5 of which are described in d[illegible]l Four of these five fistulas *occurred* after pneumonectomy or lobectomy [illegible] one following a segmental resection *Again, four of these* five specimens [illegible] studied at necropsy rather than at secondary thoracotomy They believ[illegible] the mechanism of the fistulas could be considered under two causes, either [illegible]sion by an extrinsic lesion, as a local tuberculous empyema or lymph node [illegible] factors intrinsic to the bronchus, as poor closure, extension of ulcerati[illegible] endobronchitis or delayed infection of the stump from parenchymal lesions From a consideration of the time relationships in the clinical course and th[illegible] pathologic evidence, they concluded that, in most instances, a tuberculous [illegible]npyema had preceded and contributed to the *formation* of the fistula

It may be recalled that none of these cases received *what would* be considered satisfactory chemotherapy by present standards, and *each* resection was carried out in the presence of known or probable drug resistant bacilli

The high incidence of tuberculous bronchial disease was well known in the so-called pioneer years of chemotherapy Overholt and co workers[3] (1949) reported finding bronchial involvement in 64.5 per cent of resected post-thoracoplasty specimens, while Auerbach[4] (1949) found an incidence of 42.1 per cent in one thousand consecutive autopsies on tuberculous patients.

More recently (1953) Olson, Jones, and Angevine[5] discovered some degree of endobronchial tuberculosis in 40 per cent of 602 surgical specimens. Roll[6] carried out a study of bronchial stump ulceration following resection, and noted an incidence of 24 per cent in four hundred resections. A significant finding in this series was the prevalence of stump ulceration in those patients who had drug resistant bacilli at the time of surgery.

Medlar[7] has found that true "ulcerative" tuberculous endobronchial disease is uncommon. The majority of bronchitis is a superficial mucositis resulting from the sloughing of necrotic debris from an adjacent parenchymal cavity. When the actual sloughing is reduced or eliminated by collapse, resection or chemotherapy, the secondary bronchitis subsides.

We do not concur in the rather widespread belief that most bronchopleural fistulas result from transection through unrecognized tuberculous endobronchial disease.

The acute or frank fistula in the early postoperative period may result from mechanical factors relating to the remaining lung, or to the blood supply or closure of the stump. Chronic fistulas, whether overt or occult, do not necessarily result from, or are associated with, tuberculosis. Several of our patients, and several in Murphy's report, were seen in many months, and even years, after resection, with hemoptysis or excessive cough, yet with no evidence of bacteriologic relapse.

TREATMENT

No secondary measures, whether re-treatment with new drugs, postresection thoracoplasty, or secondary resection, are as important as the original prevention of these medical-surgical failures. Our entire concern in this study has been an analysis of the factors which predispose to this complication. These will be summarized:

1. *Chemotherapy Control.*—Previous experience with pulmonary resection in patients with closed or open (cavitary) lesions, whether sputum negative or positive at the time of surgery, has yielded uniformly good results, provided drug coverage was effective.

With the exception of the patient herein reported (see Table II) who demonstrated tuberculous reactivation following excision of a noncavitary lesion, there have been no other instances of tuberculous complications in a group comprising 80 patients with closed lesions.

The results of resection in a larger group of 150 patients, who had residual annular shadows and negative sputum for three months prior to surgery, the so-called "open negatives," were equally satisfactory.[8] However, in the past three years, 8 patients treated with multisegmental resections, have demonstrated both x-ray and bacillary relapse postoperatively. In 5 of these patients, included in the present study, the tuberculous reactivation was associated with an occult segmental stump fistula. The remaining 3 patients had x-ray evidence of exudative disease in the parenchyma adjacent to the resected segments. Diagnosis of an occult fistula was not certain, however, and for various reasons, secondary resection was not performed.

A uniform finding in each patient with this complication was the demonstration of tubercle bacilli in the resected specimen, with significant resistance to one or more drugs.

Review of the bacteriologic data of each patient revealed beginning resistance to one or more drugs prior to the time of sputum conversion. Because of the absence of tuberculosis morbidity in the open negative patients with susceptible organisms prior to surgery, or in the resected specimen, it was felt that effective chemotherapy was the most important consideration for a safe resection.

Those patients who had both cavitary lesions and positive sputum at surgery exhibited a similar correlation.[9] In other words, those patients with bacilli resistant to one or more drugs had two to three times the incidence of postresection tuberculous complications as those with susceptible organisms.

Thus, the incidence of tuberculous morbidity in each group, whether sputum positive or negative, and whether open or closed lesions, although almost insignificant in the latter, appears to parallel the ultimate effectiveness of the antituberculous agents.

2. *Type of Resection.*—*Because of the anticipated and actually higher incidence* of tuberculous complications in patients with poor antimicrobial control, we believe certain operative precautions should be taken with these patients, which do not appear necessary in the group with completely susceptible organisms. These will be summarized.

1. Avoid spillage of necrotic tuberculous material. (In this event, copious irrigation of pleural space, change of gloves and suction tip.)
2. Avoid wedge or segmental resections which allow narrow clearance of cavity bearing areas and may cut across heavily seeded intersegmental planes.
3. Insurance that remaining lung tissue will rise up over and adhere to the area of the bronchial stump.
4. Measures to encourage prompt expansion and eliminate space problems, (a) reconstitution of incomplete fissures, (b) division of inferior pulmonary ligament, and (c) selective use of pneumoperitoneum.

Since the chronic occult fistulas described in this report were a complication of resection therapy, it was with some trepidation that secondary resections were advised. As mentioned, one patient died of pulmonary hemorrhage before the occult fistula was diagnosed or resection could be planned. The second patient, the only one of the group with susceptible bacilli in tissue culture, had a segmental resection as a successful secondary operation when a deep wedge had been done primarily. In the remaining 6, all with resistant bacilli in the primary specimen, secondary lobectomy was the only alternative. Each operation was difficult because of inflammatory reaction near the segmental stump and pulmonary artery. In one instance, an uncontrollable laceration in the artery necessitated a pneumonectomy (Table IV).

TABLE IV. CHRONIC OCCULT FISTULAS
SURGICAL TREATMENT—TUBERCULOUS REACTIVATION

TYPE OF SECONDARY RESECTION		CURRENT STATUS	
None	1	Dead	
Segment	1	pulmonary hemorrhage	1
Lobectomy	5	Inactive	
Pneumonectomy	1	six to 36 months	6
		Active	
		contralateral side	1

The unexpected success of lobectomy in arresting unilateral disease after a postresection tuberculous reactivation, strengthened our impression that whenever this type of bacteriologic background exists, lobectomy should be the choice at primary resection. Although the fistulous tracts were all infected with tuberculosis at the segmental stump level, it is significant that resection just a few millimeters lower; for example, at the level of the lobe bronchus did not result in any fistulas or stump ulcers.

The present status of this small group is of interest (see Table IV). Six of the group have been inactive for periods ranging from six to thirty-six months. One patient has a small superior segment cavity in the contralateral lung and is being retreated with cycloserine.

SUMMARY AND CONCLUSIONS

1. Eight cases of chronic occult bronchial fistulas are described following segmental excision of all palpable tuberculous lesions. Each fistulous tract became infected and resulted in the endobronchial dissemination of new disease in the adjacent lung.

2. The sputum of 5 patients had been negative by culture for at least three months prior to resection. Seven of the group had culture positive specimens, which yielded tubercle bacilli with equivalent or greater resistance patterns than were apparent before operation.

3. The clinical syndrome, which is notable for its absence of subjective symptomatology, is described. Recognition that such complications may occur in patients with open lesions, regardless of the sputum state preoperatively, particularly when drug resistance is apparent, will facilitate the diagnosis. Other diagnostic aids are discussed.

4. The role of a local postresection space and uncertain antituberculous drug control in the pathogenesis of chronic tuberculous fistulas and adjacent parenchymal reactivation is described.

5. Careful microscopic study of the specimens obtained at secondary thoracotomy, and the known duration of the new tuberculous lesions, indicates that all occurred subsequent to spillage from the fistulous tract. There was no evidence of endobronchial tuberculosis at the level of bronchial transection in the primary specimens.

6. Many patients with various degrees of resistant bacilli evident preoperatively do not have tuberculous complications. However, the majority of patients with these complications are found in this group.

7. This study reaffirms the importance of careful "tailored to bacteriology" surgery at the time of resection in patients with uncertain drug control. A wide, clean type of resection, usually a lobectomy, was immediately successful in this group with occult fistulas when a previous bisegmental excision had failed.

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DISCUSSION

DR JOSEPH GORDON, Albuquerque, N M—It pleases me very much to see this presentation coming out of Sunmount In 1954, at the Montreal meeting, some of you may recall that in discussion of one of the papers, I presented the information that bronchography was important as an adjunct in demonstrating a bronchial communication in any persistent space following resection. At that time, I had left Ray Brook shortly before and was then associated with the work at Sunmount as well, but was unable to present the paper formally. However, we did continue with the work at Albuquerque at the Veterans Hospital, and have found that it is indeed relatively easy to demonstrate a bronchial communication in most cases in which the pneumothorax persists This is an important feature, because as you may have seen here, and as we have had experience in the need to correct this asymptomatic space As time goes on, infection may be extended to the point where reoperation requires extensive surgery, even to pneumonectomy, to solve the patient's problem In any instance, where there is delayed expansion of the lung or persistence of space, or almost re expansion of the space but a small strip remains, it is most important to try to demonstrate by every means possible, chiefly by bronchography, the presence or absence of a bronchial fistula It is even important in instances where a so called tailoring thoracoplasty is used to obliterate the remaining space, that care be taken to demonstrate whether or not the space still persists under the thoracoplasty. This can be done with the aid of contrast medium. I believe that in any instance where the space persists, the diagnosis of presumptive bronchial fistula should be considered until such time as it is completely ruled out I am pleased to see this work so well presented today

DR ALFONSO TOPETE, Guadalajara, Mexico—I appreciate very much the opportunity of discussing this interesting paper. I believe the problem of bronchial fistula after pulmonary resection is still present, mainly in resection of tuberculous pulmonary tissue, and especially in lobectomies and pneumonectomies

I should like to say a few words about an experimental work we have been doing for the last three years in the University of Guadalajara, Mexico.

A group of 100 dogs have been subjected to pneumonectomy and after the closure of the bronchus, we then covered the stump, applying freeze-preserved (−10°) superior vena cava which is sutured to the bronchial and peribronchial tissue using fine atraumatic 5-0 Deknatel sutures (separate or continuous stitches). Groups of dogs have been sacrificed from 48 to 6 months after operation.

(slide) This is a gross specimen of an animal sacrificed 15 days after operation. We see the firm consolidation of venous tissue over the bronchial wall.

(slide) This is a microscopic section of a dog sacrificed one month after operation. We see the intense fibrous reaction which covers bronchus and venous tissue.

(slide) This is a microscopic section of a bronchial specimen of a dog sacrificed 6 months after surgery. It is interesting to note that it is almost impossible to recognize venous tissue because of the great fibrous reaction. We believe that this strong reaction which appears very early after we cover the stump with vena cava helps a great deal in obtaining a firm closure of the bronchial stump after resection. Some of the veins have been kept for as long as 100 days before use, according to our special procedure.

During the last year and one-half, we have used this procedure in 24 human patients who were operated on at Zoquipan Hospital. In those patients, we used human superior vena cava. All were tuberculous patients subjected to upper lobectomies and pneumonectomies. One patient died fifteen days following right pneumonectomy. The autopsy showed as cause of death, cardiac failure. The bronchial stump showed a good fibrous recovery.

The remaining patients are now under good control.

DR. BELL (Closing).—I do not wish to leave the impression that all postresection reactivations in tuberculosis are necessarily associated with chronic occult fistulas. They may or may not be. In many instances, however, of postresection reactivation, their presence should be ruled out if possible. We have seen chronic occult fistulas without any evidence of tuberculous activity up to two or three years postoperatively. On the other hand, they may be associated with periodic hemoptysis or secondary infection, and may need treatment. Another point is that careful microscopic examination of tissues, removed at the primary resections in this group, did not show any evidence of unrecognized endobronchial disease. It is also of particular interest that a lobectomy was successful in arresting the disease when carried out at a level only a few millimeters lower than the level of the occult fistula segmental stump, yet we had no stump ulcers or fistulas of the lobe bronchus in the series.

EXTRAPERIOSTEAL PLOMBAGE THORACOPLASTY: OPERATIVE TECHNIQUE AND RESULTS WITH 161 CASES WITH UNILATERAL SURGICAL PROBLEMS

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THE purpose of this paper is to record our experience with extraperiosteal plombage thoracoplasty in the treatment of patients with unilateral surgical problems. The application of this procedure to patients with bilateral surgical problems will be the subject of a subsequent report.

As indicated in Table I, a total of 161 extraperiosteal plombage thoracoplasties were performed for unilateral surgical problems between August, 1949, and June, 1954. Eighty-six operations were performed in two stages. The second stage consisted of resection of the previously deperiostealized ribs and the removal of the plombage material. The first rib and the transverse processes were preserved. The one-stage operation was used in 75 cases. Here the plombage material was left in place permanently. The techniques of these procedures will be illustrated and discussed later.

Age.—The age of the patients ranged from 16 to 66 years. Twenty-two per cent were over 50 years of age. Seven patients were over 60 years of age.

Sputum Status.—One hundred and thirteen patients (70 per cent) had a positive sputum. The majority of these (103) were positive by smear or concentration. Forty-eight patients had negative sputum preoperatively but 40 of these had definite cavity on the roentgenogram.

Preoperative Roentgenogram.—No cavity was visualized in 16 patients, 9 of whom had positive sputum. These cases represented largely those who previously had had extensive destructive lesions or recurrent disease. Honeycombing in the site of previously extensive disease was present in 4, 3 of whom had positive sputum. A definite cavity was present in 141 (88 per cent). The cavity size is listed in Table I. Note that most cavities were under 4 cm. in diameter. Extraperiosteal plombage thoracoplasty has not been used electively in the treatment of larger cavities.

Thus, only 8 (5 per cent) of the 161 patients had both a negative sputum and the absence of cavity on the roentgenogram. Ninety-five per cent of the patients had an open cavity and/or a positive sputum.

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Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

TABLE I. EXTRAPERIOSTEAL PLOMBAGE THORACOPLASTY, AUGUST, 1949, TO JUNE, 1954

Total = 161			
Two-stage operation		86	
One-stage operation		75	
Age of Patients 16 to 66 years			
16 to 20 years		4	
20 to 50 years		121	
50 to 60 years		29	22%
60 to 66 years		7	
Preoperative Sputum			
Positive on smear on concentrate		103	70%
Positive on culture or guinea pig inoculation		10	
Negative		48 (40 had cavity)	
Preoperative Roentgenogram			
No cavity		16	
Honeycombing		4	
Cavity		141	
1 to 2 cm.	57		
2 to 4 cm.	66		
4 to 5 cm.	14		
5 to 8 cm.	2		
2 cavities	2		
Preoperative Chemotherapy			
None		9	54%
Interrupted		78	
Primary		74 (46%)	
Postoperative Chemotherapy			
None		31 (19%)	
Less than 3 months		36 (33%)	
Over 3 months		94 (58%)	

Preoperative Chemotherapy.—Nine patients had no preoperative drug therapy. Seventy-eight had had either previous or interrupted courses of chemotherapy. Only 74 (46 per cent) were operated upon under the protection of a primary course of antimicrobial therapy.

Postoperative Chemotherapy.—Thirty-one patients had no chemotherapy in the immediate postoperative period, 36 had less than three months, and 94 (58 per cent) had over three months of drug therapy. Many of these patients, of course, had subsequent chemotherapy in an attempt to control persistently positive sputum or active disease and also for protection during subsequent resection.

TECHNIQUE

Two-Stage Operation.—

First stage (Fig. 1): The incision is made and the thoracic cage exposed as for conventional thoracoplasty. The number and length of ribs stripped of their periosteum is likewise fashioned to collapse the cavity area adequately and collapse the uninvolved lung as little as possible just as in the case of a conventional thoracoplasty. The periosteum is stripped completely from all ribs from the second rib down. However, the periosteum is stripped only from the undersurface of the first rib. The periosteum and muscle attachments on the superior surface of the first rib are left intact. The gutter area is developed completely by stripping the periosteum to the heads of the ribs and cutting the intercostal muscles. The intercostal vessels and nerves are not cut except for the first which is usually divided while doing a very modified apicolysis consisting of wiping the lung down from beneath the brachial plexus. A more extensive apicolysis is considered to be contraindicated in plombage thoracoplasty. When an extensive apicolysis is performed, the plombage material is no longer placed in the extraperiosteal space but into direct contact with all the mediastinal structures and lymphatics. It is our firm belief that this contributes to complications when using plombage material. The intercostal muscles are then cut anteriorly to avoid their suspending action. Two hundred thousand units of penicillin and 2 Gm. of streptomycin are placed in the extraperiosteal space which is now ready for the plombage material.

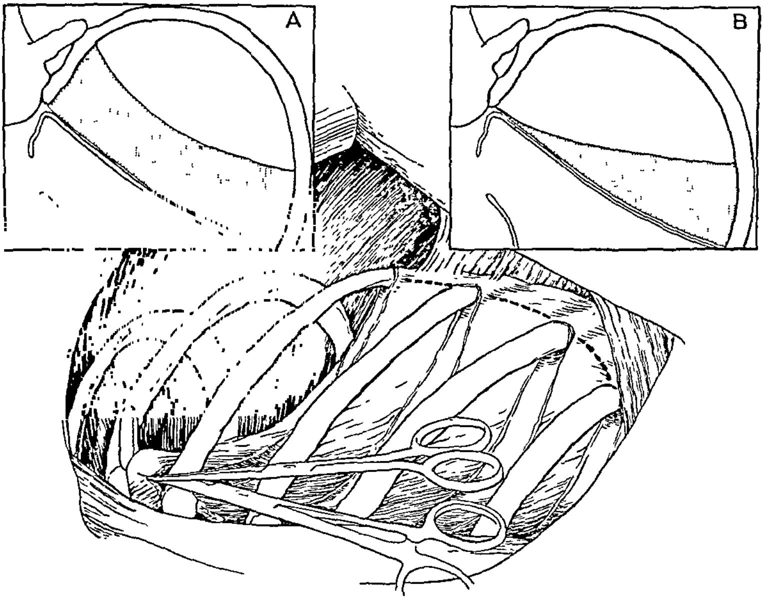

Fig. 1.—Illustration of the first stage extraperiosteal plombage thoracoplasty. The periosteum has been stripped from ribs 2 through 6 but only from the under surface of the first rib. *After the periosteum has* been stripped posteriorly to the heads of the ribs, the suspended intercostal muscles are cut as illustrated to prevent their suspension of the lung *in the paravertebral gutter. If this is not done, the collapse in this important cavity bearing* area will be inadequate (inset A) and the desired collapse (inset B) will be presented. Likewise, the intercostal muscles are cut anteriorly along the dotted lines to avoid their suspending action anteriorly.

In the case of a one-stage operation, a small strip of periosteum would be preserved on the outer surface of all ribs.

In our early experience, Lucite spheres alone were used. Later the spheres were placed in a polyethylene sheet. We now prefer to use a polyethylene

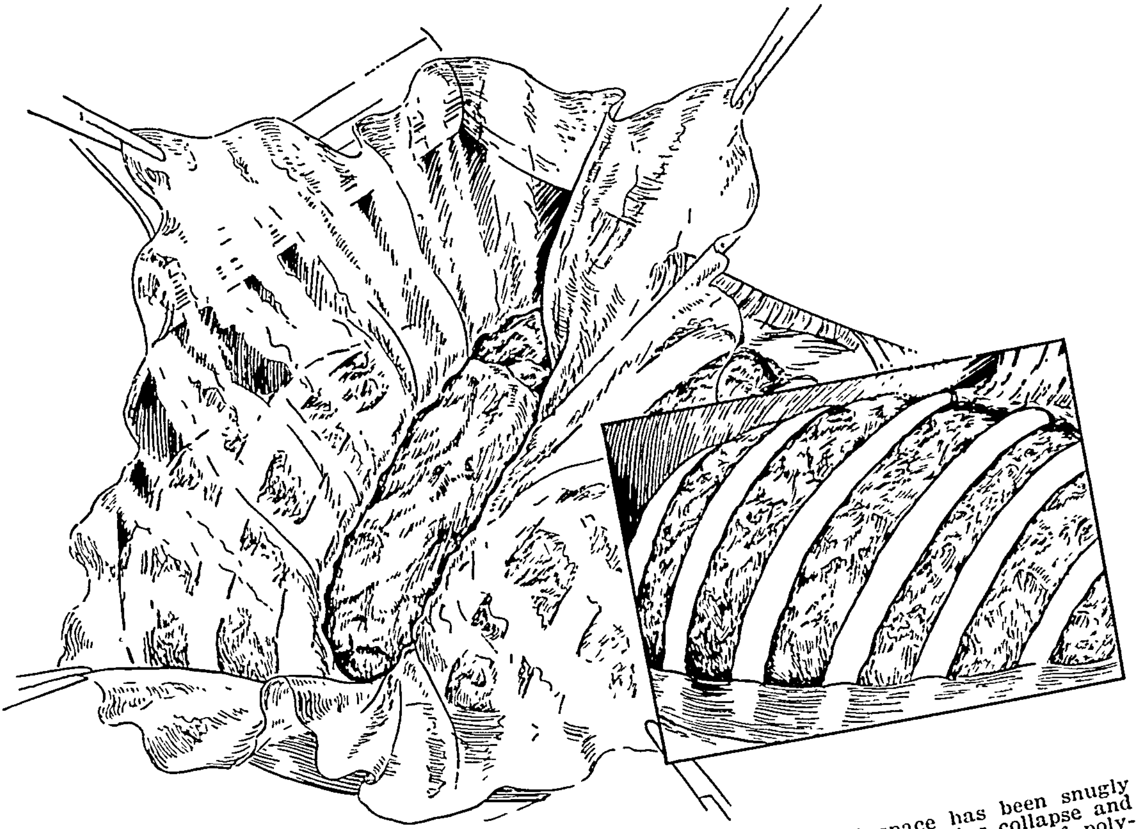

Fig. 2.—The first stage is being completed. The extraperiosteal space has been snugly filled with folded polyethylene sheets inside a polyethylene wrap. This maintains collapse and prevents paradoxical motion. Inset illustrates the final result after the lower fold of polyethylene has been placed under the upper fold which in turn has been brought down beneath the stripped ribs.

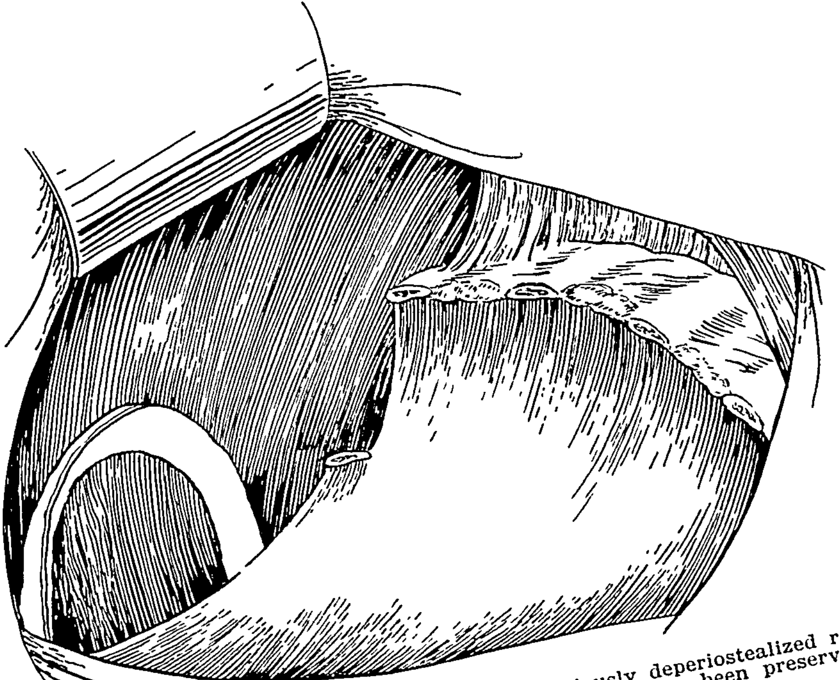

Fig. 3.—The second stage has been completed. The previously deperiostealized ribs resected. The first rib and transverse processes have been preserved.

sheet as a wrap and to use folded polyethylene sheets as a filler (Fig. 2). These create a smoother shelf, maintain the space very well, but are not so rigid as the spheres. Although we prefer the folded polyethylene sheets to Lucite spheres, our results to date have been equally good with both materials. The quantity of plombage material to use is just that which will snugly fill the extraperiosteal space and avoid creating pressure on the shelf. The wrapping is then closed around the plombage filler merely by passing the lower portion under the upper portion beneath the deperiostealized ribs. We have not found it necessary to seal the wrapping. The wound is then closed in layers.

Second stage (Fig. 3): The old scar in the skin is excised. The muscles are divided in the line of the previous incision. The deperiostealized ribs are resected from the transverse processes forward. The transverse processes with their attached ligaments and muscles and the first rib are left intact. This helps to avoid significant deformity although some scoliosis develops in every case. The plombage is removed and the number of the spheres or folded sheets of polyethylene are checked with the count recorded at the first-stage operation. A subtotal scapulectomy is performed only if indicated to prevent the scapula from riding on the costal cage. The wound is again closed in layers without drainage.

One-stage operation: This is performed in exactly the same way as the two-stage operation except for one detail. Since the ribs are to be left in permanently, a narrow strip of periosteum is preserved on the outer surface of the rib instead of stripping the rib bare of its periosteum. Our observations to date would lead us to believe that this helps to preserve the rib and prevent its degeneration as is frequently seen when all of the periosteum is removed.

COMPLICATIONS

Table II lists complications encountered and is largely self-explanatory. Attention is called to the extremely low postoperative tuberculous complication rate (0.6 per cent). This one complication consisted of perforation and tuberculous infection of the extraperiosteal space. This went unrecognized until it was discovered five months later at the time of resection which was performed because of persistently positive sputum. The second stage of the thoracoplasty was performed at the time of resection and the extraperiosteal space placed on drainage with suction for four or five days. The wound has never manifested any signs of infection since then and the patient is clinically well with a negative sputum.

The only nontuberculous infection of the extraperiosteal space occurred in a patient with a marked skin allergy which prohibited the use of any of the antibiotics as well as the usual agents used in preparing the skin for operation. He has since had the plombage removed and the second stage performed with an excellent result.

The absence of postoperative spreads or exacerbations is attributed to two factors: drug preparation and coverage, and the lack of paradoxical motion.

A.

B.

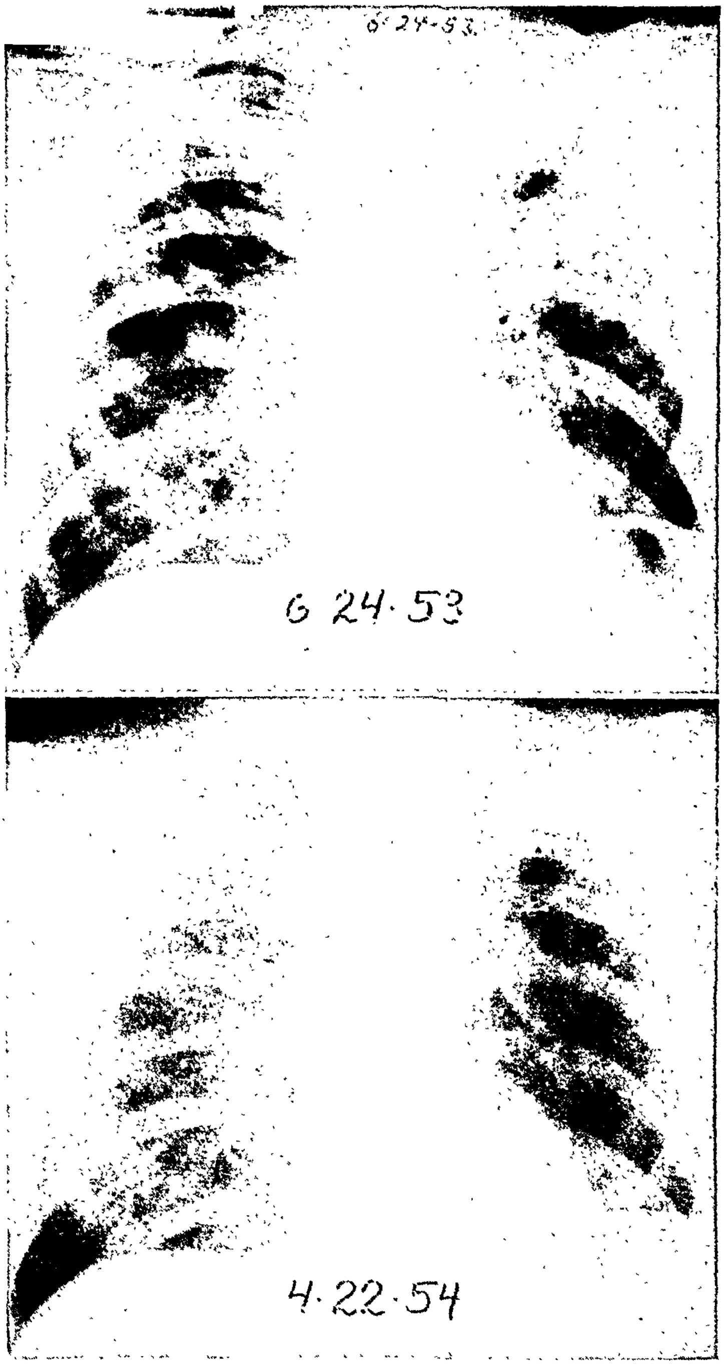

Fig. 4.—Two-stage extraperiosteal plombage thoracoplasty. *A*, Roentgenogram made at time of admission on June 24, 1953, revealing scattered infiltration throughout the upper half of the right lung and the entire left lung. A 4 cm. cavity is present in the left apex.

B, Roentgenogram of April 22, 1954, after ten months of antimicrobial therapy. A residual 3 cm. cavity persists in the left apex. The remainder of the disease has responded well to treatment. Sputum was negative.

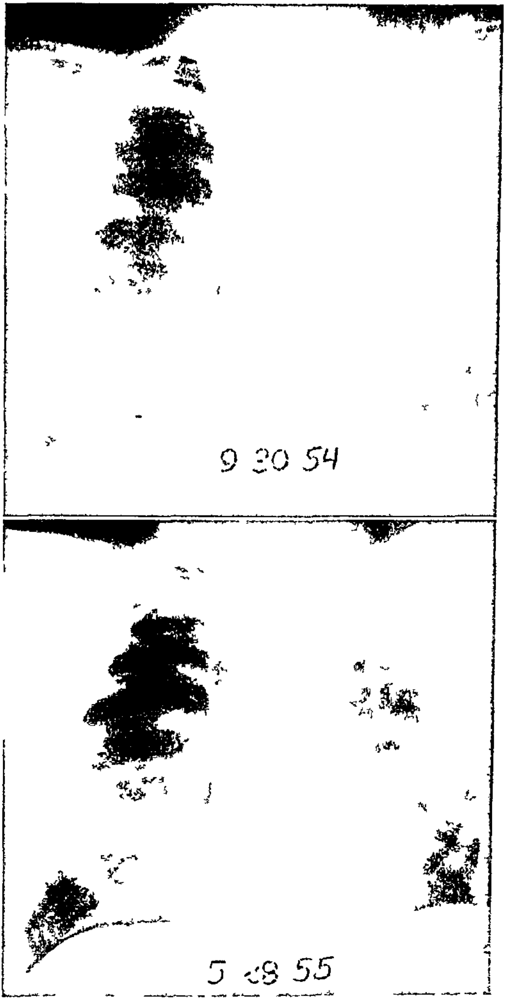

Fig 4.—*Cont'd* *C*, Reontgenogram of Sept 30 1954 showing the polyethylene plombage in place. This was taken six months following the first stage and just before the second stage.

D, Roentgenogram of May 28 1955—seven months following the second stage. Note the degree of scoliosis present. Also the preserved first rib and transverse processes.

COMMENT. This patient was a 38 year old man. He has been well since his discharge from the sanatorium. He had no postoperative chemotherapy except for one week after the first stage. The second stage was performed after careful sputum studies revealed that the procedure had been successful. The vital capacity was reduced from 3 450 c.c. to 3 100 c.c. and the maximum breathing capacity from 110 to 98 L. per minute.

Today the surgeon no longer has to accept the patient with large quantities of sputum and with his tracheobronchial tree flooded with infected secretions. This probably is the dominant factor in preventing spreads. The absence of paradoxical motion afforded by the plombage also is an important factor. There can be no doubt that the effectiveness of the cough mechanism is greater and the interference with respiration is less following plombage thoracoplasty than following one of the conventional type.

TABLE II. COMPLICATIONS

*Postoperative complications—3 (1.9%)	
Tuberculous—1 (0.6%)	
Perforation and infection of extraperiosteal space	
Nontuberculous—2 (1.2%)	
Staphylococcus aureus infection of extraperiosteal space	
Transient uremia	
Late complications	
Tuberculous—22 complications in 20 patients (12%)	
Ipsolateral exacerbation	7
Contralateral exacerbation	11
Wound infection	2
Renal tuberculosis	1
Ipsolateral spread	1
Nontuberculous—1 (0.6%)	
Wound infection	

*Postoperative period—60 days.

Late tuberculous complications, especially contralateral exacerbation, has constituted the biggest problem in this group of patients. This has been our experience with any surgical procedure which is used in treating really significant tuberculosis. In our opinion, this is the result of the fact that many of these patients had extensive contralateral lesions preoperatively at the beginning of their treatment. All except one of the contralateral exacerbations occurred in an area of previous disease. Seven of the 11 patients with contralateral exacerbations were eventually controlled, 4 by antimicrobial therapy and 3 by further chemotherapy and resection. The other 4 were classified as having active tuberculosis at the time of this report in June, 1955. Since then, one has had a plombage thoracoplasty and one a segmental resection. The other 2 are considered to be salvable.

The low percentage of exacerbations on the side of operation has been in keeping with our experience with any type of permanent collapse therapy. Patients with initially successful results stand the test of time exceedingly well. Four of the 7 patients with ipsolateral exacerbations were resected with good results. Two have active disease, one of which is salvable and the other being hopeless because of advanced age and limited respiratory reserve. One is known to be alive but the follow-up data in this patient is inadequate.

The statistics on late complications include those of both the plombage thoracoplasty and all subsequent resections. The one ipsolateral spread and both wound infections occurred in patients who had subsequent resection, the first of these three complications occurring in a patient resected in another institution. These represent the only complications encountered in the 21 patients subjected to later resection.

Attention is again called to the fact that one half of the late complications occurred in the contralateral lung.

DEATHS (Table III)

There were no postoperative deaths. This, plus the fact that tuberculous complications occurred in only one of the 161 patients, speaks for the safety of this procedure. This is especially significant when one considers that 95 per cent of the patients had either an open cavity, a positive sputum, or both. It is also significant when one considers that only 46 per cent of these patients were operated upon under the protection of their first course of antimicrobial therapy. These facts are in sharp contrast to most resection series in the literature which contain a high percentage of patients with closed lesions and negative sputum operated upon under the protection of their first course of chemotherapy.

The five late deaths were all due to nontuberculous causes. Three patients had sudden deaths caused by coronary occlusion. One patient died of metastases from a previously resected carcinoma of the breast. The other died of a severe undiagnosed enteritis in another hospital. Only one of the five late deaths occurred in a patient with uncontrolled tuberculosis at that time.

Not a single death has occurred in the postoperative period following either the plombage thoracoplasty or a subsequent resection. No deaths due to tuberculous infection have occurred early or late.

TABLE III. DEATHS

Postoperative deaths		0
Late deaths		5 (3%)
Coronary occlusion	3	
Metastatic carcinoma	1	
Enteritis	1	

RESULTS (Table IV)

One hundred and thirty-two (82 per cent) of the 161 patients had completely satisfactory results with plombage thoracoplasty. Their sputa have remained negative and their clinical status satisfactory since the operation.

Twenty-nine (18 per cent) of the plombage thoracoplasties were considered to be failures. Of this group, 22 were considered to be initial failures, the patients' sputa never converting following operation. In one, the sputum remained positive for five months and then converted. In one, the sputum remained intermittently positive until the time of his death of coronary occlusion five and one-half years later. Another had one positive sputum by guinea pig inoculation eight months after operation and has been negative ever since. One remained positive for two years and then converted with further sanatorium care and chemotherapy. One has been clinically well since operation but his sputum has never converted. The remaining 17 have been subjected to resection—pneumonectomy in 2, lobectomy in 12, and segmental resection in 3. Fifteen of the 17 had completely satisfactory results following resection. One patient, a drug addict, has been lost to follow-up. One has active contralateral disease.

Seven patients considered to have a successful result initially had a late exacerbation on the side of operation. Four of these were resected—one by pneumonectomy, one by lobectomy, and 2 by segmental resection. These 4 patients are all well. One of the remaining 3 has active disease but is considered to be salvable. One is considered to be hopeless because of her age (71) and limited respiratory reserve. One patient known to be alive and active refuses to answer our follow-up letter and, therefore, cannot be classified.

In summary, plombage thoracoplasty has been successful in controlling the lesion for which it was performed in 132 patients (82 per cent). It failed to do so in 29 patients (18 per cent). Of the latter group, 19 were salvaged by resection and 3 by further antimicrobial therapy. Thus the lesion for which operation was indicated was eventually controlled in 154 (95.6 per cent).

TABLE IV. RESULTS

Total cases			161
Successes			132 (82%)
Failures			29 (18%)
a. Initial failures		22	
b. Failures due to exacerbations		7	
Control of the ipsolateral lesion			
By plombage alone	132 (82%)		154 (95.6%)
By later resection	19		
By later chemotherapy	3		

FOLLOW-UP (Table V)

In June, 1955, a follow-up study of the 161 patients was carried out. The follow-up period ranged from one year to five years and ten months; was over three years in 89 patients (55 per cent); and over two years in 132 (82 per cent).

Five (3 per cent) patients died in the late follow-up period—3 of coronary occlusion, one of metastatic carcinoma, and one of enteritis. One patient, the drug addict, has been lost to follow-up. The remaining 155 patients (96 per cent) are known to be alive and an accurate follow-up was available in 152.

TABLE V. FOLLOW-UP, JUNE, 1955

Total 161 patients			
Dead		5 (3%)	
Lost to follow-up		1	
Living—inadequate follow-up		3	96%
Living—adequate follow-up		152	
Clinically well—negative sputum	145		
Clinically well—positive sputum	1		
Active disease	6		
Duration of follow-up period			
Longest	5 years 10 months		
Shortest	1 year		
over 5 years	30		
4 to 5 years	26		
3 to 4 years	33		
2 to 3 years	43		
1 to 2 years	29		

The classification of these 152 patients represents the opinion of the physician or clinic now caring for them. One hundred and forty-five patients were classified as clinically well with negative sputum. This group represents 90 per cent of the total 161 patients and 95 per cent of the living patients with an adequate follow-up. Of the remaining 7 patients, one is clinically well but has a positive sputum and 6 have active disease. All except one of these are considered to be salvable.

DISCUSSION

Our experience with extraperiosteal plombage thoracoplasty began in August, 1949, after Woods, Walker, and Schmidt[1] had introduced the procedure to our clinic one year before. Our earlier cases were all of the two-stage type of operation. The original procedure of Woods, Walker, and Schmidt was modified by leaving the plombage in place for a minimum of two months and preserving the first rib and transverse processes at the second stage to avoid significant deformity. As our experience grew, we learned that the plombage material could be left in place for longer periods with safety. Eventually the second stage was delayed for four to eight months until the success or failure of the procedure in controlling the disease was established. If successful, the second stage was done. If unsuccessful, resection was performed and the second stage of the thoracoplasty completed at the same time. Thus, the patient's surgical treatment was accomplished with two operations regardless of the success or failure of the plombage. Subsequent resection in these cases has proved to be extremely safe and successful. In the 21 patients subjected to later resections, no postoperative deaths occurred and only one postoperative tuberculous complication took place. This was an ipsolateral spread following lobectomy performed in another institution. Nineteen of the 21 patients are now well. Plombage failures can be treated more easily and successfully than resection failures.

The first one-stage extraperiosteal plombage thoracoplasty was performed in November, 1951. A total of 75 are in this report. The longest follow-up is three and two-thirds years. Twenty have been followed for more than three years and 63 for more than two years. In the postoperative period, only one tuberculous and one nontuberculous infection of the space has occurred. These 2 cases have been described previously under complications. There have been no late infections of the space. Likewise, there has been no evidence clinically or by direct observation at operation of infection of the extraperiosteal space at the time of the second stage in the other 86 cases. In these cases the second stage was performed from two months to four and one-half years following the first stage. In addition, the fibrin and serum from the space have been studied in the last 21 consecutive cases: 14 by smear and culture; one by smear and guinea pig inoculation; and 6 by all three methods. These have all been negative.

The lack of late complications in the extraperiosteal space is attributed to three factors: one, the careful selection of patients; two, avoiding the use of the conventional type of apicolysis; and three, the type of plombage material used.

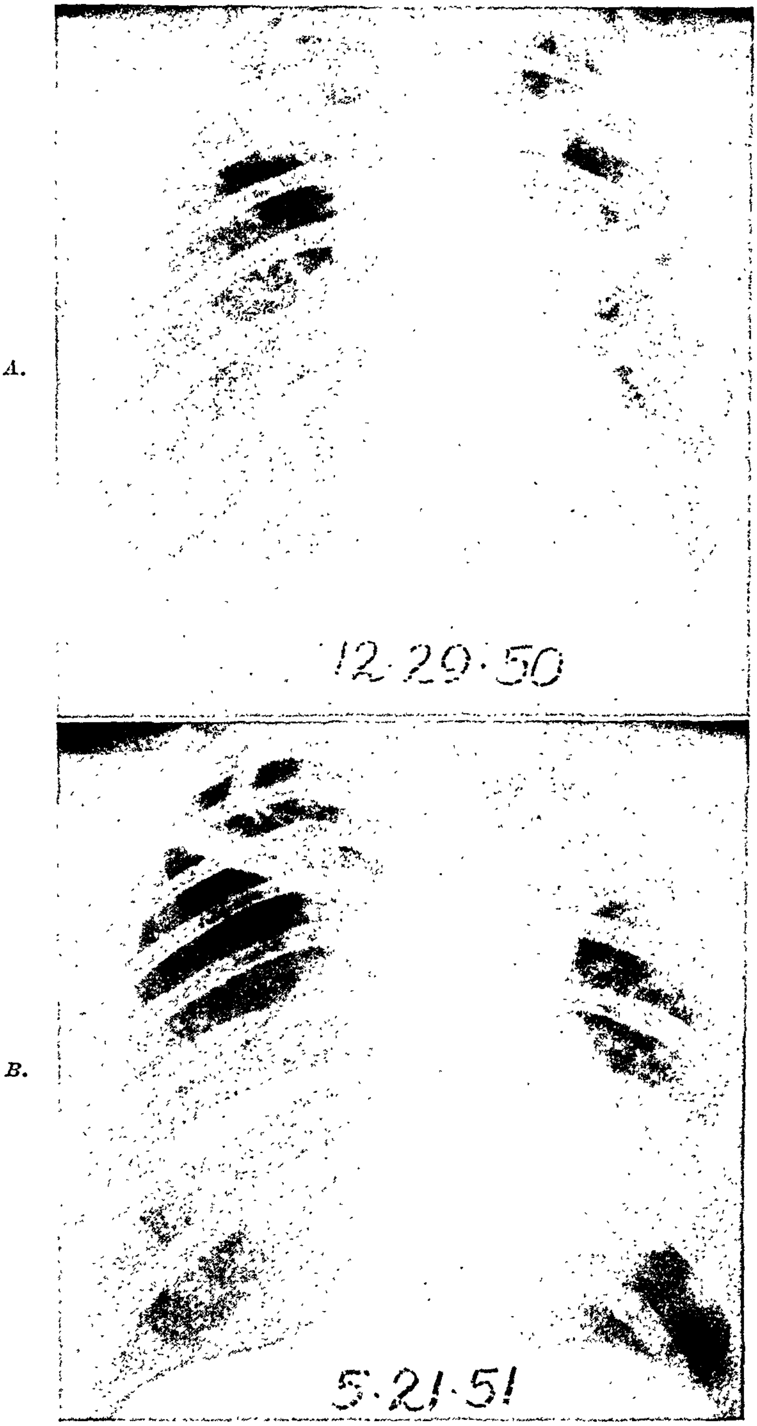

Fig. 5.—Below-up thoracoplasty with extrapleural mobilization of cavity. *A*, Roentgenogram of Dec. 29, 1950, showing widespread bilateral disease with a 4 cm. cavity in right upper lobe and a giant cavity in left upper lobe.

B, Preoperative oblique roentgenogram of May 21, 1951. The cavity in the right upper lobe is now closed. A giant cavity is still present in the left upper lobe. Note also the involvement of the superior segment of the left lower lobe and scattered nodulation throughout basal segments. The sputum was positive on smear.

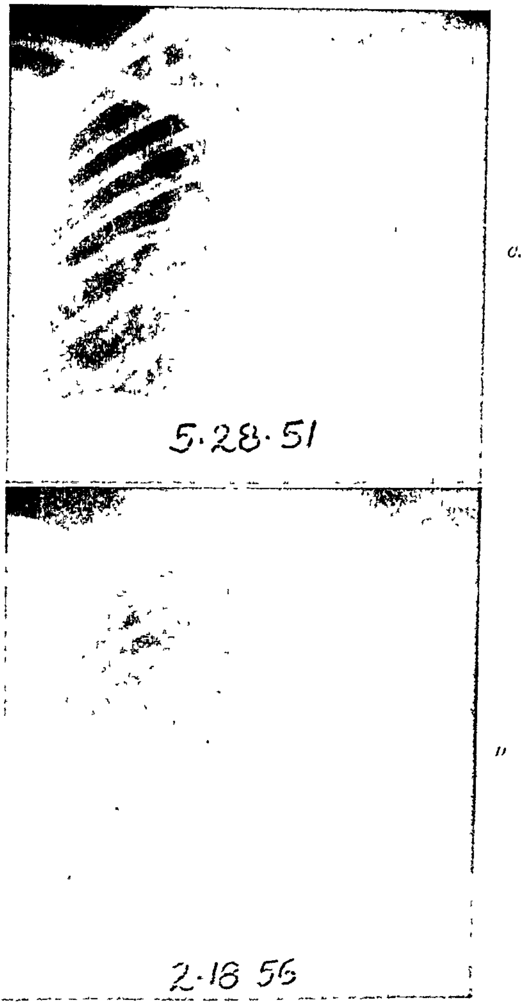

Fig. 5.—*Cont'd.* *C*, Roentgenogram of May 28, 1951, just six days following lower stage
thoracoplasty and mobilization of the cavity. Note the rapid decrease in size of cavity.
Roentgenogram of Feb. 16, 1956—four years and eight months following operation.
the transverse processes have been preserved.

MENT. This 25-year-old woman represented a serious problem. She had had exten-
the right side. Certainly no resection short of left upper lobectomy and resec-
segment of the left lower lobe could have been considered for the left
ectomy might have been necessary if exploration had been performed because
in the inferior segments. stage thoracoplasty under these circum-
ed by us over either of these resections.

cavity is considered to be a contraindication to plombage thoracoplasty.
has been well since operation. Her sputum converted in one month. She
children and has been able to care for her family.

Plombage thoracoplasty is indicated in our scheme of therapy for cases with cavities of 4 cm. in diameter or smaller. Peripherally located, thin-walled cavities and larger cavities are considered to be contraindications. Such cases are treated either by resection or by staged thoracoplasty. Most of the staged thoracoplasties are performed from below up, with mobilization of the cavity area by extrapleural dissection at the time of the first and lower stage (Fig. 5).

The only apicolysis permitted with plombage thoracoplasty is the division of the first intercostal bundle and wiping the lung from behind the brachial plexus. A more extensive apicolysis is considered to be absolutely contraindicated because this places the plombage in direct contact with the mediastinal structures including its numerous lymphatic nodes and channels. In our opinion, this predisposes to infection of the space.

A satisfactory plombage material must be easily sterilized and easily removed from the extraperiosteal space at any time. Either Lucite spheres or polyethylene sheets inside a polyethylene wrapping meet these requirements admirably. They can be sterilized by soaking in aqueous Zephiran for twenty-four hours. They can be removed from the extraperiosteal space at any time, even a few years later, with great ease. The various sponges do not meet these fundamental requisites, in our opinion, and have not been used.

However, in spite of the lack of infectious complications in the extraperiosteal space thus far, much more time will be required before a final evaluation of this problem can be made. Every surgeon knows that the presence of a foreign body can lead to delayed infections several years later. Because of this one factor, this report regarding the one-stage plombage operation must be considered a preliminary one. With regard to the two-stage operation, however, we feel that we can state without hesitation that the plombage can be left in with safety for at least eight months. At the present time, it is our policy to perform the two-stage operation upon the younger patients and reserve the one-stage procedure for those over 45 years of age or for those with bilateral problems.

If there is no uncontrolled or threatening lesion other than the one for which thoracoplasty is being performed, chemotherapy is terminated one week following operation. Our experience has led us to believe that lesions controlled by permanent collapse stand the test of time exceedingly well without the aid of antimicrobial therapy. If chemotherapy is continued in the postoperative period, many of the failures are camouflaged, the sputum being negative even though the offending cavity may still be open. We prefer to discover the failures early and proceed as early as possible with resection in such cases. We have had no reason to regret this policy.

The advantages of plombage over the conventional staged thoracoplasty are self-evident. The surgical program is reduced to one or two operations even in the case of failures where the patients later require resection. In addition, the second stage is performed months rather than weeks following the first stage, providing the patient with more time for recuperation. The total collapse is accomplished at the first operation which brings about more rapid conversion of sputum. The two-stage operation results in a mild scoliosis but no significant clinical deformity because of the preservation of the first rib and transverse processes The one stage operation produces no deformity There is no postoperative paradoxical motion This causes less disturbance in respiration and makes the cough mechanism more effective As a result, the postoperative course of these patients is unusually smooth It is rare to see retention of secretions or severe dyspnea even in the bad risk patients The only special care required by these patients is the routine aspiration of the extraperiosteal space on the second day and as needed thereafter to avoid pressure These patients recuperate faster and require less postoperative care than any group undergoing surgical treatment for pulmonary tuberculosis

At a recent meeting of the New York Up State thoracic surgeons, Gaensler[7] outlined four undesirable effects of operation upon pulmonary function (1) interference with the negative intrapleural pressures, (2) pleural reaction, (3) paradoxical motion of the chest wall, and (4) unpredictable complications Certainly, plombage thoracoplasty produces none of these undesirable effects It does not interfere with the intrapleural pressures or produce pleural reaction unless the pleural cavity is entered as a result of a technical error Paradoxical motion is avoided Unpredictable complications are truly rare and are less a problem with plombage thoracoplasty than with any other procedure we have used Plombage thoracoplasty stands out in sharp contrast with resection which produces all of these undesirable effects except paradoxical motion This is a factor of extreme importance when treating patients with limited pulmonary function

We have found the functional loss with this procedure to be relatively small and predictable Forty patients have had ventilatory studies preoperatively and again postoperatively after three months The average loss of vital capacity was 477 c c and the average loss of maximum breathing capacity was 17 4 L The loss of maximum breathing capacity ranged from 0 to 10 in 57 per cent, 10 to 15 in 25 per cent, 15 to 20 in 10 per cent, and 20 to 32 L in only 8 per cent

Plombage thoracoplasty has several disadvantages The difficulty with interpretation of the postoperative roentgenogram is disturbing With the plombage in place, no type of examination by x ray including laminography, is of value The underlying lung just cannot be visualized In cases with persistently positive sputum, the other areas of the same lung and the contralateral lung must be evaluated in making decisions about further therapy With present techniques, the migration of spheres or polyethylene packs is no problem The two great disadvantages of the one stage operation are the presence of a foreign body with its potential of erosion and infection and the fact that periosteum does not regenerate a significant amount of bone when in contact with the plombage material To date, we have had very little trouble with erosion and infection but, as stated before, much more time will be required for the final evaluation of this factor It has been surprising to find little or no regeneration of rib where the plombage material is in contact with the periosteum The musculo periosteal shelf becomes thickened but remains flaccid even a few years later

It is quite evident that more time will be required before the one-stage plombage thoracoplasty can be recommended as a safe procedure because of the presence of the foreign body. However, the two-stage operation can be recommended at present as a safe and effective procedure with a small and predictable loss of function. It avoids the four undesirable effects upon pulmonary function outlined so well by Gaensler[2] and, for this reason, is particularly suited to the treatment of cases with limited pulmonary function.

This is a simple operative procedure. There can be no question that it is safer than resection in the hands of any surgeon when used in the treatment of cavitary disease. This is especially true in patients with cavitary disease with organisms partially to completely resistant to the antimicrobial agents. The high mortality and morbidity rates associated with resection in this type of case have been presented in admirable fashion by Bell[3] and Murphy.[1] Because plombage thoracoplasty does not involve the handling, incision, and suturing of infected lung tissue and bronchi, we consider it a procedure of choice in treating such patients. However, we would not like to convey the idea that this procedure is used only in the resistant cases. We have such faith in the effectiveness and lasting cure afforded by permanent collapse procedures that they are frequently used in preference to resection even in the better risk patients.

In the chemotherapy era, resection has rightfully become the most popular type of surgical treatment for pulmonary tuberculosis. The resection statistics in the literature, however, are misleading. They are loaded and diluted with a high percentage of closed lesions, wedge and subsegmental resections of extremely small lesions, and patients receiving their first course of drugs. When patients with persisting cavity and positive sputum after long-term antimicrobial therapy and patients with tubercle bacilli partially or completely resistant to the drugs are analyzed, the mortality and morbidity are truly significant.[3, 4] Likewise, the statistics dealing with pneumonectomy and resection exceeding a lobe are much less favorable than those with resection of a lobe or less.[4]

In the drug era, we have lost sight of the fact that collapse therapy procedures also have become safer and more effective. Indeed, most of the concepts expressed today focus attention on the preceding era when drugs were not available and case selection was less than ideal by necessity. There is too little recognition of the fact that permanent collapse is very effective and the successes stand the test of time exceedingly well. So long as the surgeon is called upon to treat not only the ideal case but also those with limited function and resistant organisms, collapse therapy must play an important role in the surgical program. In fact, unless collapse procedures are used, many patients will be denied treatment since resection is not applicable to all cases. If resection is used to the exclusion of all other procedures, some patients will be subjected to relatively dangerous operations when simple collapse procedures could have been used with great safety and with the expectation of success in a high percentage of cases.

SUMMARY

Experience and results with 86 two-stage and 75 one-stage extraperiosteal plombage thoracoplasties have been presented.

There were no postoperative deaths following this procedure or following 21 resections performed upon failures Five late deaths resulted from nontuberculous causes. No deaths have resulted from tuberculous infection

Tuberculous complications occurred in only one case (0.6 per cent) in the postoperative period Late tuberculous complications developed in 12 per cent One half of these were in the contralateral lung

The lesion indicating surgery was controlled in 82 per cent by plombage thoracoplasty alone. Of 29 failures, 22 have been salvaged by resection and further chemotherapy

Ninety per cent of the total 161 patients and 95 per cent of the 152 with an adequate follow-up are well

These results have been accomplished in spite of the fact that 95 per cent of the patients had positive sputum and/or cavity on the preoperative roentgenogram and only 46 per cent were operated upon with the protection of an original course of chemotherapy.

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DISCUSSION

MR. WILLIAM P. CLELAND, London, England—It is a great privilege to be here today and to be allowed to participate in your meeting I last had the privilege of addressing your Association in 1951 at Atlantic City, when I mentioned my earlier experiences with plombage operations which I had performed up to that time I think it is proper that those of us who have had a fairly lengthy experience with this operation should report our views from time to time, particularly as regards the long term follow up

Dr Wilson's presentation, I think, was an extremely admirable one and he brought out one or two very important and significant points The first of these was that the plombage patients were significantly different from the majority of those considered suitable for resection Of my own material (which now amounts to 340 personal cases) over a third were considered entirely unsuitable for any other form of surgical treatment. I think that is an important point, as Dr. Wilson rightly pointed out.

With regard to the future of this procedure, there are two points I should like to mention (1) How does this procedure compare with the ordinary standard method of surgical collapse therapy, and (2) what is the incidence of complications related to the use of this sort of material?

(Slide) This represents the present number (340 operations) up to the end of 1955 You will see that 238, or 70 per cent, were regarded as satisfactory, a term used to cover a variety of things such as cavity closure, negative sputum, ability to work, and so forth.

These 238 patients were satisfactory without any additional treatment. Some 12 per cent required further treatment such as prolonged chemotherapy, conversion into a thoracoplasty or subsequent resections, before they were satisfactory. So that 82 per cent of this group are regarded now as satisfactory. Of the 6 unsatisfactory patients at the present time, there are 3 with persistent cavitation; 2 of those will probably be suitable eventually for resection, one is quite hopeless for any further treatment. There are quite a number, unfortunately, (17) that are untraced. Of those who have died (35), you will notice that only 4 died in the early postoperative period, that is, within a month or six weeks of operation, and 31 have died subsequently. This rather high incidence of later deaths is, I think, related to the type of patient we are treating, although 14 died from unrelated causes such as lung cancer and from coronary occlusion, while 17 died directly or indirectly from pulmonary tuberculosis.

(Slide) This is a comparison between plombage and the Semb type of thoracoplasty; these thoracoplasty figures represent operations carried out at a slightly earlier period than the plombage procedures and are not, therefore, strictly comparable, particularly in that the amount of streptomycin available and employed was probably very much less. But you will see that there is no appreciable difference between the two groups. I would not say that plombage is better, but neither is it significantly worse. One striking difference, however, is the difference in early mortality. There are 29 cases in the thoracoplasties compared with 4 with plombage, but the reverse is true with late mortality, namely, 15 for thoracoplasty and 31 for plombage.

(Slide) You will note we have had 18 patients (5.3 per cent) with space infection. I have regarded all cases except the obviously pyogenic ones as being tuberculous in origin whether or not we can find and culture tubercle bacilli. You will notice that most of them are in the early cases. The decrease in complications of this sort is due, I think, to the employment of very much more streptomycin, and also to improvement in technical procedures and to better selection of cases.

(Slide) This slide indicates the interval between operation and onset of infection. Most of these occur within the first two years of operation, but there is one rather disturbing group here which occurred four to six years after the procedure. That is the only feature of this operation which is a little bit worrying, that infection can occur quite late after the operation.

(Slide) One important feature about space infection, however, is that when it does occur it is not necessarily the end. Provided it is recognized reasonably early, it is a simple and straightforward matter to deal with, and should finish with a quite satisfactory final result. Of the early pyogenic infections, they have presented no real problem provided they are recognized and treated by removing the plomb and doing a thoracoplasty. Of the late tuberculous infections, 14 of the patients had a thoracoplasty and 11 of these healed by first intention; 3 had a sinus for some two or three months afterward. Five patients have subsequently died either from widespread tuberculous disease of the same or the opposite lung, or from unrelated causes, not necessarily related to the tuberculous infection. In one case, the plomb alone was removed without thoracoplasty, and one case was treated by aspirations and chemotherapy. Both have done well, but I do not recommend it as a routine measure. Two had nothing done; both were unrecognized at the time, and one of them developed amyloid disease and by the time he came back, it was quite impossible to help him.

It is always very important to try and determine the reasons for failure in any procedure and plombage is no exception. With regard to the failure of the operation to deal with the initial situation, that is, where there is persistence of cavitation, I believe that the most important single factor is the presence of bronchial disease. We have already heard a little bit about that and I think in the paper following this, we shall hear a great deal more about this very important factor. Of the cases we have resected after plombage, I think some 60 or 70 per cent have shown significant endobronchial tuberculous lesions which I am sure have contributed to the failure of the operation. With regard to space infection, I believe the most important single factor is the opening up and cutting through of infected tissues and I would prefer not to use a plombage in any case where the apex of the lung is very adherent, where one is almost certainly cutting through infected lymphatics, I think under those circumstances it is much wiser to do a standard thoracoplasty. Another factor in the production of space infection is the presence of uncontrolled to inadequately controlled disease beneath the plombage, which was the case in about 50 per cent of our patients. I now make it a practice to carefully assess, by all means at my disposal, the condition of the lung beneath the plombage six months after the operation and, if things are not entirely satisfactory, then I proceed without delay to carry out a resection if such is practical.

DR. JOHN B. PETTER, Rutland Heights, Mass.—I appreciate the privilege of discussing Dr. Wilson's excellent paper, and would like to present briefly our experience at Rutland Heights Veterans Administration Hospital. Our operative technique is similar, however, we prefer the polyethylene spheres introduced by Lucas and Cleland in 1950. These have the advantage that they may be sterilized by boiling. We do not remove the spheres unless infection occurs. In the past four years we have restricted the use of plombage to the poor risk patients in whom we believed resection was contraindicated, due to the presence of drug resistant organisms, advanced age, borderline functional reserve, or unfavorable disease distribution.

(Slide) We have performed 73 polyethylene ball plombages on 66 patients during the past four years. In the same period, 292 resections were done, a ratio of 4 to 1. Eleven patients were open negative at the time of surgery, 55 were open positive, of which 43 demonstrated drug resistance. Sixty two patients had bilateral disease. In addition to the 7 patients who had bilateral plombage, 8 others had previous contralateral resection of thoracoplasty.

(Slide) The surgical complications were limited to two fistulas, seven space infections, and two postoperative bleeding problems. The space infections healed promptly on removal of the balls and overlying ribs.

(Slide) The effect of plombage on pulmonary function is of particular interest since many of these poor risk patients have a limited reserve. Although some patients exhibited a gain in maximum breathing capacity (MBC) and vital capacity, most had small losses with a mean loss of 11 L. MBC and 461 c.c. vital capacity. These losses are slightly smaller than the mean losses following resection of from three to five segments in uncomplicated cases.

(Slide) Of the 55 patients open positive at the time of surgery, 29 or 53 per cent became closed negative within eight months. Of the 26 remaining positive 19 had late resections which were all well tolerated, with 17 promptly becoming negative.

(Slide) A one- to 4-year follow-up of these poor risk patients indicates that 57 are now closed negative, 40 achieving this by plombage alone, 17 with additional late resection. Seven remained positive. There were no surgical deaths, there was one late tuberculous death from a fistula, and 2 nontuberculous deaths from hepatitis and carcinoma of the pharynx.

We agree that plombage is a safe procedure, particularly useful in increasing the salvage rate of the poor risk chemotherapy failures.

DR. PAUL DE CAMP, New Orleans, La.—I certainly have enjoyed these presentations and we, too, occasionally find patients in whom we are afraid to do resections. I would like to show a film of a procedure that we learned from Dr. Fernando Paulino in Brazil, which has been presented here before. In this procedure a conventionalized Semb type of apicolysis is performed and then, for collapse, very minimal foreign body material is used.

The apicolysis has been performed, the apex of the lung and overlying tissue is brought up and now a soft cotton ligature is placed around the involved lung and overlying tissues. The last one is placed around the lung and overlying tissues below the lowest point of significant palpable disease. At the present time we find we are using the procedure for very much the same kind of case that the extraperiosteal plombage is used for. These are patients who have resistant organisms and in whom a resection would be either too extensive or too hazardous, so this procedure is performed. We use three or four of these ligatures. In this case, portions of the first, second, third, and fourth ribs have been removed; normally, we now leave in the first rib.

We have performed this operation about fifty times. In five instances, it has been done as a bilateral procedure for bilateral disease. The chief limitation of this operation technically is that it cannot be applied to disease below the hilum. However, there can be included in it the apical segment of the lower lobe. It can also be applied if one gets inside, planning to do a resection, and finds that the case is unsuitable for resection. If there is a majority of the disease as cavitary lesions above the hilum, these ligatures may be applied to the lung above the hilum. In our hands, in this series of 50 cases, we have had one intrapleural pyogenic infection and one subscapular space pyogenic infection. These responded to drainage alone. We have had no tuberculous infections either within or without the pleural cavity. I regret that others have not been so fortunate, and I wish I knew the reason why they have had difficulties so that I could tell you how to avoid them.

DR. ELLIOTT MICHELSON, Baltimore, Md.—I should like to congratulate Dr. Norman Wilson and also Mr. Cleland on their excellent results with the extraperiosteal Lucite plombage thoracoplasty, a procedure which may well supplant the standard thoracoplasty. In line with the Presidential Address by Dr. Meade yesterday on the "Forgotten Men in Thoracic Surgery," it is interesting to note that Dr. Oughterson and Dr. Harvey in 1930 suggested the extraperiosteal space filling as a method of lung collapse therapy. They used a rubber bag, infection developed, and they were discouraged from further use of the procedure. Since that time a great number of surgeons have placed diverse materials in this space, including air, fat, muscle, paraffin, and plastics of all kinds. At Sunmount Veterans Hospital, in 1948, we were interested in some type of collapse procedure for patients with borderline ventilatory function and bronchospasm. The temporary Lucite plombage thoracoplasty operation was therefore developed. At the first operation maximum collapse is obtained by the Lucite spheres in the extraperiosteal space, and six weeks later the ribs and spheres are removed. During 1948 and 1950, 25 patients with maximum breathing capacity ranging from 20 to 40 L. per minute received this procedure with no mortality aside from one death from meningoencephalitis. Function test by Dr. George Wright revealed minimal loss of ventilatory function. The final results were similar to those of Dr. Wilson and Mr. Cleland. I should like to emphasize that this operation should be the procedure of choice in patients with diminished ventilatory function since there is no paradoxical motion in the immediate postoperative period, adequate cough is possible, pulmonary function is preserved, and no chest or spine deformity develops. Whether the plombage should be removed at a second operation depends upon the surgeon's consideration of the calculated 2 to 5 per cent risk of tuberculous infection in the extraperiosteal space.

DR. FELIX A. HUGHES, Memphis, Tenn.—We too have had a limited experience with plombage thoracoplasty. I reviewed our figures for the past three years and found that we have performed 188 plombage procedures on 153 patients during that time; 66 other types of thoracoplasty have been employed of which only 14 were the regular modern type of thoracoplasty. During the same period, 130 pulmonary resections were performed. I think the reason the plombage procedures exceeded the resections was that there had been an accumulation of cases of bilateral pulmonary tuberculosis that we had not considered to be suitable for resection. Many of the points I wanted to make have been adequately covered; for example, the maximal preservation of pulmonary function and a very low operative mortality—we had one death following 188 procedures.

We were at first very skeptical about plombage since a foreign body is introduced into the thoracoplasty space. Our early results were so good, however, that we thought we should not deny this procedure to many patients who have such extensive disease that no one would do a resection. We have therefore extended the indications for its use to many bilateral cases with cavities on both sides. As you know, the results obtained in any surgical procedure for tuberculosis will depend in the main on the type of patients that are started with So we did not anticipate a conversion of sputum of 85 to 90 per cent in this type of patient In cases of a minimal lesion we have obtained around 85 to 90 per cent conversion One other point is that resection is the best form of treatment if it is applicable The plombage thoracoplasty has served to round out the surgical therapy of cases seen at Kennedy VA Hospital

DR EDWARD A GAENSLER, Brookline, Mass—I should like to congratulate Dr Wilson on his [illegible] results and also on his courage to continue a program of surgery which runs [illegible] to prevailing trends At the Sanatorium Division of the Boston City Hospital [illegible] Dr [illegible] service, we also started plombage in the fall of 1949 and to date have performed [illegible] operations on 131 patients Our patients also, for the most part, have been in the older age group, nearly all sputum positive, drug resistant, and with far advanced disease Our results also have been good, although not as outstanding as Dr Wilson's because a [illegible] number of bilateral cases were included, and because the selection for this procedure was often made by exclusion, no one dared to do a resection There have been only [illegible] deaths in 150 operations, in spite of our training program where many plombages were the first or second experience for the particular surgeon

Unlike Dr Wilson [illegible] have removed the plomb whenever possible at the end of four months This was, first because we originally used a reactive plomb, namely, Lucite spheres within a rubber sleeve, second, because of an early visit to our hospital by Mr Cleland who told us of his incidence of 5 to 10 per cent late infections, and third, because of the findings in our patients by Drs Desforges, Gibbons, and Strieder, that a positive culture could be obtained from the subcostal space in 38 per cent of our patients, four months postoperatively (J Thoracic Surg 28 636, 1954) That this policy of conversion has been justified is borne out by our figures There have been no subcostal empyemas in over 1[illegible]0 cases where the plomb was removed as scheduled In patients in whom for some reason or other we could not remove the plomb, the incidence of subcostal tuberculous infection and empyema has been 15 per cent

I feel that subcostal plombage should be considered as an important alternative to resection, particularly because we will see more and more older patients with far advanced disease resistant to all drugs and with complicating "compensatory" emphysema In these patients, subcostal plombage can be performed with a lower mortality, without the complication of bronchopleural fistula, and also with less loss of function, because in these patients the disease is usually distributed regionally rather than segmentally

DR ROBERT FOX, Chicago Ill—At the Municipal Tuberculosis Sanitarium in Chicago we have been using a modified thoracoplasty with extraperiosteal plombage since late 1[illegible]50, first at the instigation of Dr William Adams in Chicago and with gradual modification over a period of years Since we started this procedure we have completed about 664 thoracoplasties with plombage, at least 25 with bilateral plombage I should like to present some of our results in operations done before 1955, giving us at least a 15 month follow up inasmuch as we reviewed our figures just this last month This totals some 531 thoracoplasties with plombage For purposes of study we have divided these patients into three categories arbitrarily, the first group, those in whom we thought thoracoplasty would be a definitive procedure in that we had an excellent chance of getting the patient well, in many of these we felt resection was contraindicated The second group are those in whom there was large cavitation, or because of the location of the cavity, we thought thoracoplasty had less than a 50 per cent chance of doing the job and yet wanted to do something to help the patient, and the third group, those in whom we thought we had practically a zero chance patients with extensive disease, and yet we wished to help if possible

(slide) So far as complications and mortality were concerned, there were five deaths within three months of the time of operation, or just under 1 per cent As Dr Wilson indicated, some of these patients are old and many have rather [illegible] respiratory reserve

There were 26 late deaths or 5 per cent, and about one half were from nontuberculous causes. So far as postoperative atelectasis and spread or exacerbation elsewhere, there were 5 of these or just under 1 per cent; all responded to treatment.

(Slide) So far as the plomb material itself, or as Dr. O'Brien said some years ago, the "garbage" put into the extroperitoneal space; there were 46 patients or about 8.5 per cent who had sufficient subscapular fluid to necessitate one or more aspirations. There was only one early infection, and by early I mean within three months of operation. There were three late infections; in none of these did we get tubercle bacilli—they were all pyogenic infections; all responded promptly to removal of the pack. There were 82 who had sufficient migration of the wax into the soft tissue to necessitate removal of the pack. All these healed by first intention.

(Slide) Our results are as follows:

Group I.—274 cases, 91 per cent are alive and well today.
Group II.—220 cases, 74 per cent are alive and well.
Group III. (salvage)—57 cases, 25 per cent are alive and well.

We believe these figures speak for themselves, and we urge strongly that thoracoplasty be used in those patients in whom resection carries an increased risk of complication or failure.

DR. FRANCIS PHILLIPS, Bartlett, Alaska.—We also became interested in this type of procedure at the Seward Sanatorium, after seeing the work of Dr. Adams and Dr. Lee in Chicago in 1952. We have done only 150 cases. Of that number there were 12 in which we had some form of complication. In the early cases, in my enthusiasm with the wax I added a little more than I had prepared space for. When cicatrization had finally occurred, after several months a little outcropping of the wax occurred in the incision. This complication was simply remedied under local anesthesia. We had one case in which the wax was removed early because of a massive infection. This patient developed a *Streptococcus viridans* hemolytic bacteremia in spite of being heavily treated with antibiotics at the time. However, he is well today with a negative sputum and is working as a shoemaker.

There are three points in these procedures that I would like to discuss. This is a procedure that we now do under local anesthesia. It takes an hour to an hour and a half. The patient is up and walking around in the evening, after operation in the morning, with little suffering. I think this is important. Another point that I am beginning to think is important is the ease of the procedure for the surgeon. Those of you who are backed up by great universities with magnificent anesthesiology departments and skilled anesthesiologists have nothing to worry about. But in Alaska, I have to choose procedures that are easy to do and which spare the patient's life in the operative procedure itself. Also, in Alaska it has been calculated that it is costing us, in terms of *arresting* the disease, and I think that is the only category in which we can talk about tuberculosis (I think it is time we quit talking about the cost per day, and face it as the cost of arresting the disease), it is costing us, including social welfare, transportation and all incidental expenses, from $15,000 to $17,000 a case. That is under the old regimen. Now, with this operation, it is not unusual for us to get a patient into the sanatorium who will be there from one to three weeks, have the operation, and when he is going to a community where outpatient treatment is available, he will be discharged in four to six weeks to outpatient care. This is a tremendous saving in the cost of the treatment. This also can be measured in terms of hospital costs. It is much cheaper to do an operation that does not require the use of blood and a lot of extra nursing care. These patients have a minimum of postoperative complications. They require no special nursing care and the surgery is easier for the patient generally.

DR. WILSON (Closing).—When one expects to have his head chopped off, it is comforting to find that so many others are doing the plombage procedure with good results. I should like to re-emphasize that we are talking about unilateral surgical problems, and that the majority of our cases had cavities of 4 cm. or less in diameter. I realize that Dr. Strieder, Dr. Gaensler, and their associates have used this procedure in patients with more extensive disease. I believe that this must account for the difference in our experience with infections in the extraperiosteal space. However, after they reported their experiences, we studied cultures from the spaces in many cases anywhere from two months to four and one-half years following the first stage and have been unable to find a single positive culture or guinea pig infection.

We also recognize the potential dangers of the foreign body, and for this reason perform a two-stage operation with removal of the plombage material in the younger, good-risk patients. The plomb is left in place in the older patients, in those with low pulmonary reserves and in those with bilateral problems.

We feel that permanent collapse is capable in itself of giving permanent control of a lesion if an initial success is accomplished. For this reason we prefer to use antimicrobial therapy only for one week following operation unless there is a contralateral lesion of significance that requires drug therapy. This enables us to discover the failures early and proceed with resection at an early date.

Finally, we should like to emphasize that good results with this or any other procedure will not be accomplished if it is used only as a salvage procedure.

BRONCHOGRAPHIC STUDIES AS A GUIDE TO THE SURGICAL TREATMENT OF PULMONARY TUBERCULOSIS

F. J. PHILLIPS, M.D.,* ANTHONY LALLI, M.D.** (BY INVITATION), AND
WALTHER BUHLER, M.D.*** (BY INVITATION)
BARTLETT, ALASKA

THE purpose of this presentation is to emphasize the importance and diagnostic value of bronchography in the surgical treatment of pulmonary tuberculosis. The average case of pulmonary tuberculosis is no longer a treatment problem with our present antimicrobials and improved sanatorium armamentarium. However, the unknown pathologic ravages of the inadequately treated cases and the so-called old chronic cases are many fold and frequently unexplored. At the Seward Sanatorium, it has been found expedient to do bronchography almost routinely in all cases before any type of surgical treatment is initiated. The current, frequent finding of active tuberculous foci in resected specimens in patients with consistently negative sputums and the finding of active foci of tuberculosis in lungs apparently clear to x-ray studies as reported by Logan,[1] add additional importance to more intensive diagnostic bacteriologic and roentgenologic study. Buckles and associates,[2] from the Franklin Sanatorium, published a most impressive study on the value of bronchography including the pathogenesis of certain types of bronchiectatic lesions. Our studies are similar but lack the pathologic study of resected specimens. The problem of tuberculosis in Alaska has been so overwhelming that only recently have we been able to initiate studies evaluating our treatment efforts. We have no resident pathologist in all Alaska in civilian practice.

At the Seward Sanatorium, all patients are routinely bronchoscoped soon after admission. In skilled hands, bronchoscopy is a harmless procedure and frequently uncovers unsuspected problem lesions early in the management routine. Likewise, bronchography is employed freely as a diagnostic procedure. Normally, patients scheduled for bronchography are first bronchoscoped in order to effect bronchial cleansing. In addition to ordinary bronchial aspiration, a 2 per cent solution of ephedrine sulfate in saline as a mucosal astringent or medical bronchial dilator agent is injected through the bronchoscope and the bronchi leisurely cleaned by aspiration. The bronchi are routinely mapped out under fluoroscopic observation as illustrated and discussed in Di Rienzo's *Radiologic Exploration of The Bronchus.*[3] This is

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signally important since many irregularities that appear in the dynamic action of breathing are not manifest in the static film. Iodochlorol is used as the contrast medium injected through an ordinary rubber urethral catheter which is inserted through the bronchoscope at the time of the bronchoscopic aspiration. Lipiodol has also been used but there is no difference in the results and the Iodochlorol is more economical. Except in cases of obstructive bronchitis, the radiopaque material is almost completely disgorged in a few days. We have had no complications from its use. All patients except very young children are bronchoscoped under topical anesthesia. We use 2.5 per cent cocaine routinely in a quantity sufficient to produce good anesthesia; usually 4 to 6 c.c. Our native patients are unusually cooperative in all these procedures. Patients are preoperatively sedated with appropriate doses of Nembutal and codeine sulfate. Liquid nourishment is permitted up to one hour previous to the examination.

In the past seven consecutive years, 276 such bronchograms have been made, of which, 240 were in patients of known tuberculosis.* There were 112 males and 128 females in this study. There were 69, or 28.8 per cent, with bilateral lung involvement of some degree of bronchiectasis. Involvement in one lung only was found in 94 cases, or 34.1 per cent. There were 77 in the series without morphologic evidence of bronchiectasis. Hence, of the cases studied, 66.9 per cent had bronchiectasis in some recognizable degree. Since any significant amount of bronchiectasis may reasonably categorize a tuberculous patient as a candidate for resection, we have not further classified the cases as to type of bronchiectasis in this discussion. The type varied from cylindrical to large pendulous sacs.

There were only 29 cases in the series with obvious lower lobe involvement. Finding the bronchiectasis mainly in the upper lobes was initially a surprising observation, but apparently this is not unusual in pulmonary tuberculosis and well may have some significance in the etiology of the disease. On the basis of bronchoscopic observations, we have made a tentative division of the cases into 2 groups: Group 1, those without visible evidence of stenotic bronchitis and Group 2, those with such evidence. There were only 9 cases in Group 1. These 9 cases have bronchograms similar to W. E. (Fig. 1, *1*). This Eskimo girl came from a large family all of whom have had tuberculosis. Because of tuberculosis mortality in the family and geographic distances in Alaska, all members of the family have not been bronchographically studied. However, a brother and a sister, now alive with minimal arrested tuberculosis, did not have evidence of bronchiectasis. Hence, the apparent cystic disease in W. E. is probably not a familial characteristic.

Confluent active tuberculous involvement of the bronchi is seldom observed in our patients. In over a thousand bronchoscopic examinations, ulcerative lesions have been noted in only 2 patients. Scarring of the bronchial mucosa has been observed in many patients. In the absence of ectasia of the more distal bronchial divisions, this has not been a serious treatment problem either in the medical management or in the postoperative vigil following thoracoplasty or resection. We have not been able to relate this finding to the course of the disease except that our cases are predominantly chronic because the general hospitalization program has been grossly inadequate for the number of people afflicted. Until recently there has been a long waiting period before hospitalization. It would appear that the patients had either died or developed a favorable resistance to their disease through their own immunologic potential.

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*We are indebted to Dr. Frank Maresh for the studies done in 1949 at the Seward Sanatorium.

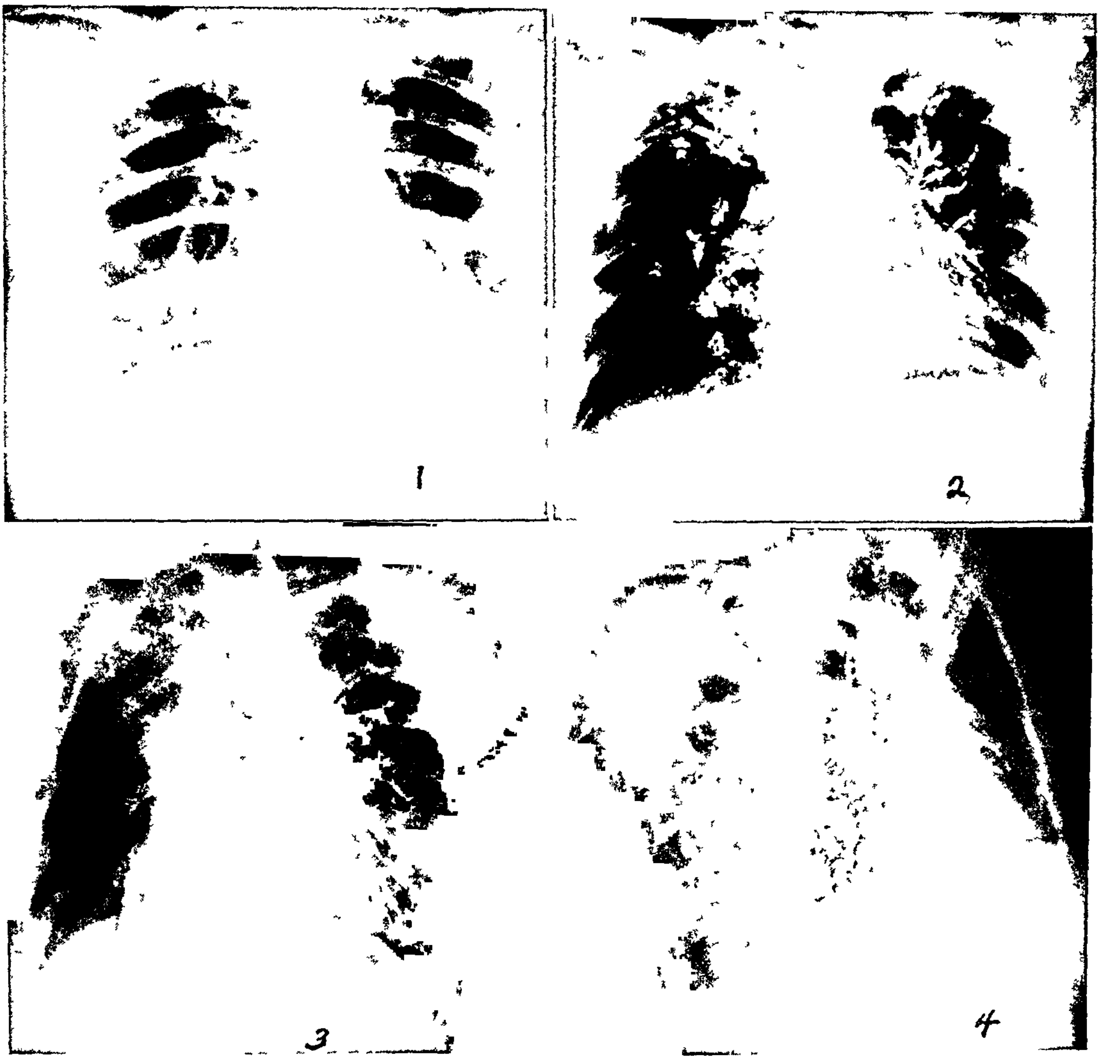

Fig 1.—Case 1, W. E. *1*, Posteroanterior 72-inch film before bronchogram. *2*, Anteroposterior 30-inch film. *3* and *4*, Opposite oblique 72-inch films.

CASE REPORTS

CASE 1.—W. E., aged 29, full Eskimo. This case presents a serious treatment problem. In our judgment, surgical resection is indicated on the basis of the ectasia, but untenable because of the existence of the extensiveness of the involvement. Although she is ambulatory and has a sputum negative for acid-fast bacilli in repeated concentrate and culture studies, a slight cold has normally made her an invalid for many days She is then obviously dyspneic to the extent of cyanosis on exertion without obvious evidence of pneumonic changes in x ray studies at the time She is being kept on an expectant antibiotic treatment basis as a client in the vocational training division of the Sanatorium, but not as a Sanatorium patient

CASE 2—A W, aged 24 This patient had a negative sputum on admission probably resultant from outpatient antimicrobial treatment while waiting for hospitalization At the initial bronchoscopic examination, bronchography was included because of the suspicious

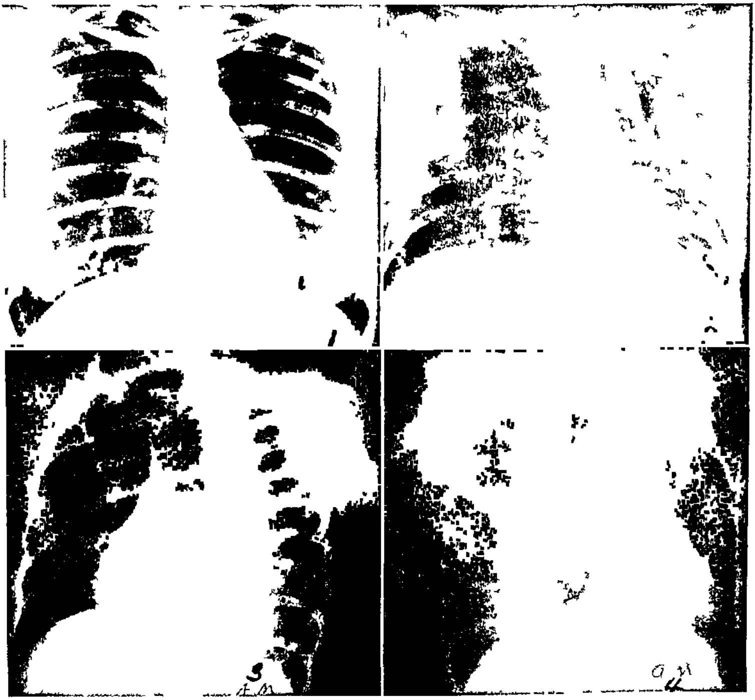

Fig 2—Case 2 A W 1 Posteroanterior 72 inch film before bronchogram 2 Anteroposterior 30 inch film 3 and 4 Opposite oblique 72 inch films

shadows in the right lower lobe area However, bronchography revealed bronchial obstruction in the left upper lobe and ectasia in the superior segment of the lower lobe There was old confluent scarring of the left main stem bronchus without stenosis which we interpreted as old confluent healed tuberculous bronchitis Left upper lobectomy and segmental resection were done two months ago The sputum has continued negative This case dramatically demonstrates the treatment evaluation importance of bronchography Without the bronchogram, she would likely have been discharged lacking the surgical treatment only to be readmitted at a later date with more extensive ectasia

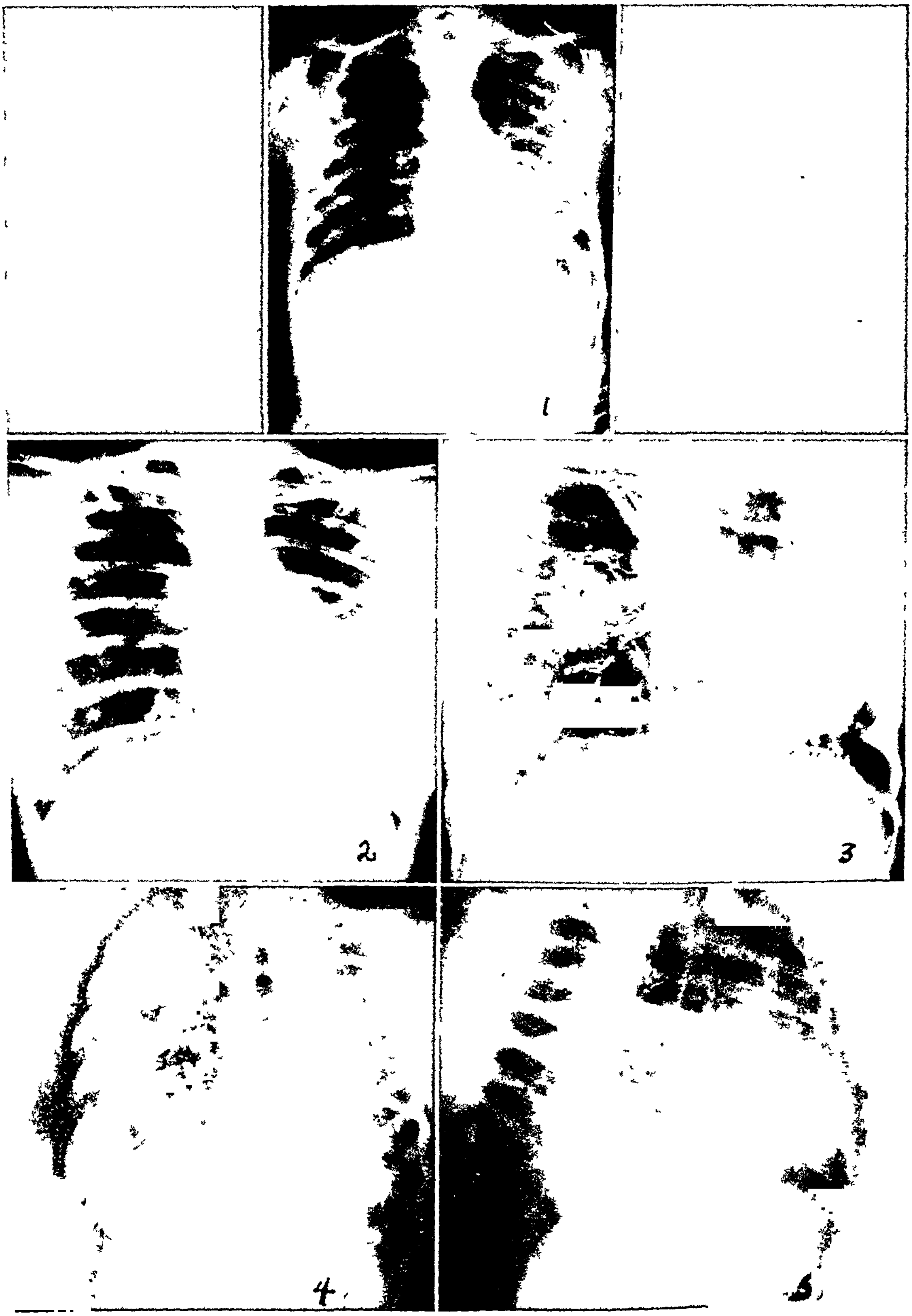

Fig. 3.—Case 3, L. J. *1*, Posteroanterior 72-inch film, 1949. *2*, Posteroanterior 72-inch film before bronchogram. *3*, Anteroposterior 30-inch film. *4* and *5*, Opposite oblique 72-inch films.

CASE 3—L. J, aged 14, Alaskan Indian This girl has been hospitalized since 1949 or since age 7. Fig. 3, *1*, although a poor film, reveals no disease eight years ago Serial x rays reveal progressive extensive bilateral involvement that defied all treatment procedures. Bronchoscopic examinations revealed confluent scarring of the right upper lobe bronchus, but no stenosis. The left lower lobe was similar The bronchograms support this observation. Both the right upper and the left lower lobes are obviously of no respiratory value to her. Resection of the left lower lobe was done two months ago Her postoperative course was uneventful. Right upper lobectomy is still to be done The sputum is and has been negative to concentrate and culture for two years

DISCUSSION

These cases are representative of the types of lesions frequently found in Alaskan patients when adequately studied. They are very informative examples of the value of bronchography. Although, in cases of bronchiectasis of nontuberculous type we are conservative in doing surgical resection, we believe that these patients who have once had a sputum positive for acid fast bacilli should have the advantage of resection of the involved areas if feasible from the respiratory reserve evaluation. Also, many of our patients return to remote areas where they may be visited by itinerant nurses only as often as every three to six months. Certainly, in the light of studies indicating the questionable arrest of cases even though sputum studies are negative, it is advisable to do resections when the indications are present as discussed in this presentation.

CONCLUSIONS

1. Bronchography is a desirable procedure in the determination of the proper treatment to be followed in pulmonary tuberculosis
2 Bronchography is a relatively innocuous procedure in careful, skilled hands.
3 Photographs of x-ray films demonstrating informative bronchography in pulmonary lesions are included with case comments.

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2 Buckles, M G, Potts, W. L, Davidson, H. R, and Neptune, W. B: Bronchography in Pulmonary Tuberculosis, With Histopathologic Correlation in 82 Resections, Am Rev. Tuberc 64: 394, 1951.
3 Di Rienzo, S: Radiologic Exploration of The Bronchus, Springfield, 1949, Charles C Thomas, Publisher.

DISCUSSION

DR JOHN W BELL, Sunmount, N Y—I wish to compliment Dr. Phillips on these excellent results in the face of considerable economic handicaps with this group of patients in Alaska I would like to emphasize the great value of bronchography preoperatively in planning the extent of pulmonary resection. We can get an estimate of the probability of doing some type of resection from preoperative x rays, but actually knowing whether you are going to have to do more than an upper lobectomy, say, including the middle or superior segment of the lower lobe, often can be determined only at operation and sometimes even that is difficult

(slide) In this instance, we had considered doing a left upper lobe procedure, either a segmental resection or a left upper lobectomy for a 2 or 3 cm cavity in this area How ever, bronchography demonstrated crowding and clubbing of the left lower lobe bronchi. We believed that a pneumonectomy would probably be necessary and that the patient would not tolerate resection well because he had contralateral cavitary disease and limited respiratory function.

(slide) This is a preoperative bronchogram. A right upper lobectomy was carried out in this patient. You can see the unrecognized ectasia of the lower lobe existing at that time.

(slide) This same patient, a young Negro, came back eighteen months later with this bronchogram. The basilar segmental bronchi were so-called "sacs of pus." This was a nontuberculous secondary infection of a pre-existing bronchiectasis. We completed a pneumonectomy on this side.

DR. RICHARD H. MEADE, Grand Rapids, Mich.—While I was in Paris last June, Dr. Mathey took me to a tuberculosis sanitarium where he carried on his work, and I was very much interested in the radiology laboratory. Not only were they doing bronchograms on all patients before deciding on resection, but they were combining tomography with bronchography. Another point I think is worth mentioning. Dr. Bell mentioned that he used Dionosil. While I was in Davos, Switzerland, last summer, I had the pleasure of visiting Dr. Iselin, and he showed me the beautiful bronchograms that he had made with the use of Dionosil. I attempted to use it myself on my return but got into great difficulty. Then an article appeared in *Diseases of the Chest* on this subject, in which nothing was said about the preparation of the Dionosil. To those who know how to use it, what I say is superfluous, but for those who do not know, if you don't heat the syringe and if you don't heat the Dionosil, it is just like trying to inject barium sulfate.

DR. F. J. PHILLIPS (Closing).—Thank you very much, Dr. Bell and Dr. Meade, for your encouraging comments. We have not tried Dionosil, mainly because we have had such good success with Iodochlorol, and because of the difficulties in getting the material. Economy is something to be considered up there where we have not too much money. I am encouraged that so many people are so enthusiastic about bronchograms, and I would like to say that I think what has held up bronchography more than anything is the old wives' tale that we all heard many years ago, that if you dared to get iodine near a patient with tuberculosis he would automatically get a fulminating spread. Obviously, this is not true.

ESOPHAGEAL EXCLUSION FOR PERSISTENT FISTULA FOLLOWING SPONTANEOUS RUPTURE OF THE ESOPHAGUS

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SPONTANEOUS rupture of the esophagus was almost uniformly fatal from the time it was first described by Boerhaave in 1724 until Eliason and Welty[1] reviewed the literature in 1946. However, during the past ten years many patients have been treated successfully and there has been increasing interest in this subject. It is now quite widely recognized that an early diagnosis of spontaneous rupture of the esophagus can usually be made, even though the symptoms are very similar to those of other serious conditions which occur much more commonly, and that immediate thoracotomy with closure of the esophageal perforation and adequate drainage of the chest is the treatment of choice.

The clinical picture is one of acute severe pain in the retrosternal area and perhaps epigastrium which often is secondary to vomiting following a large meal or drinking spree. The diagnosis is apt to be confused with coronary occlusion, a dissecting aneurysm of the aorta, or a perforated peptic ulcer below the diaphragm. The patient's clinical picture is one of a major catastrophe. The diagnosis of spontaneous perforation of the esophagus is usually confirmed by an x-ray examination. Mediastinal emphysema or air or fluid in the pleural cavity should substantiate the diagnosis. The most common mistake made is probably arriving at a diagnosis of acute coronary occlusion and deciding that the patient is too sick to have an x-ray examination, the correct diagnosis being made only after subcutaneous emphysema appears in the neck or at autopsy.

If empyema develops following spontaneous rupture of the esophagus, either because the defect is not sutured or because the suture line breaks down, some patients can be treated successfully by providing adequate drainage of the lower portion of the thoracic cavity. The fistula seals over and the drainage tract is obliterated in a manner similar to that following traumatic perforation of the cervical esophagus. Persistence of an esophageal fistula in the cervical area is rare and has not occurred in our experience. In the thorax, on the other hand, particularly following spontaneous perforation of the esophagus, a fistula may persist in spite of apparently adequate drainage and the application of suction.

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The purpose of this paper is to call attention to the principle of exclusion from the intestinal tract of that portion of the esophagus involved, as a means of overcoming the mediastinal and pleural infection. Three patients are reported who had a persistent fistula following spontaneous rupture of the esophagus. The first patient died in spite of the fact that apparently adequate drainage of the chest was provided. The second and third patients appeared to be running the same downhill course despite apparently adequate drainage. The thoracic esophagus was excluded from the stomach and cervical esophagus. This appears to have been a lifesaving measure for both patients.

CASE REPORTS

CASE 1.—M. L., aged 59, was operated upon in another hospital on Jan. 14, 1954, because of severe acute symptoms and signs high in the epigastrium which were thought to be due to a perforated peptic ulcer. The upper abdomen was explored through a right rectus incision and no abnormalities were found. Postoperatively he got along fairly well but on the third or fourth day began to get short of breath and it became evident that he had a large right pleural effusion. Creamy pus was aspirated from the chest and he was transferred to the Hospital of the University of Pennsylvania for further care. On admission he appeared to be acutely ill but not desperately so. An air-fluid level in the lower portion of the mediastinum suggested the possibility that he had had an esophageal perforation.

A thoracotomy was performed the following day, five days after the first operation. There was thick creamy pus occupying the lower third of the right hemithorax and a perforation of the esophagus, one inch long, was found on the right lateral wall of the esophagus about three inches above the diaphragm. The esophageal defect was closed with the hope that healing might take place in spite of the intense inflammatory reaction which was present. The mucous membrane adjacent to the defect did not appear to be inflamed. The involved portions of the right lung were decorticated and all the fibrin clots and exudate were cleared out of the lower portion of the thoracic cavity. Two large drainage tubes were inserted and the thoracotomy incision was closed.

For three or four days postoperatively it appeared that the right lung remained well expanded with the aid of suction and that there was no further leakage from the suture line. By the end of the week, however, drainage through the thoracotomy tubes had increased and it was evident that the suture line had not held. A gastrostomy was performed for feeding purposes. The amount of drainage from the chest tubes varied but most of the time it was large in amount and much of the time gastrostomy feedings were noted in the drainage bottles. Protein hydrolysates and plasma were administered intravenously in large amounts. The electrolyte balance was maintained without great difficulty but the patient lost weight steadily. The possibility of isolating the thoracic esophagus from the cervical esophagus and stomach thereby diverting his salivary and gastric secretions away from the fistula tract was considered but by the time the decision was made to take such a step, the patient had deteriorated beyond hope for another procedure. He died about three and one-half weeks after the attempted suture of the esophageal defect. On post-mortem examination there was no evidence of undrained pus, but the drainage tract (empyema cavity) along the diaphragm was quite large and evidently accounted for the extensive protein loss. The esophageal defect was only one centimeter long.

Comment: This man appeared rather robust on admission but went downhill rapidly and died in three and one-half weeks despite adequate drainage.

The continuing soilage of the thoracic cavity with salivary and gastric secretions kept reactivating the empyema and mediastinitis with subsequent loss of large amounts of protein.

Case 2.—P. K., a 41 year old white man, experienced very severe epigastric pain followed shortly by collapse after eating a large dinner and vomiting on July 22, 1954. This was diagnosed as an instance of acute coronary occlusion and appropriate treatment for this diagnosis was given until the following day when chest films were taken and revealed a left hydropneumothorax. A No. 20 catheter was inserted into the left pleural cavity to relieve dyspnea and the patient was transported sixty miles to the Hospital of the University of Pennsylvania where a left thoracotomy was performed that evening, approximately twenty four hours after the onset. He was in an extreme degree of peripheral vascular collapse and was in semicoma at the time of operation. His chances of survival did not seem good.

The left pleural cavity contained purulent material in addition to food particles, such as peas, in large amounts. The esophageal perforation was on the left lateral wall about three inches above the diaphragm. The area of perforation in the mediastinal pleura into the left pleural cavity was about four inches in length and the periesophageal tissues were severely inflamed, appearing black and necrotic in places. The entire left pleural cavity showed evidence of intense inflammation with erythema and engorgement of the subpleural blood vessels. Food particles and exudate were removed and the left pleural cavity was extensively drained. The patient survived this procedure and responded in a gratifying manner to antibiotics and general supportive therapy but it was soon evident that the closure of the esophagus was not successful. On the fifth postoperative day a Levin tube was passed into the stomach and gastrostomy feedings were given through the tube until the patient no longer tolerated its presence. It was removed and a gastrostomy was performed on Aug. 17, 1954, care being taken to pass the gastrostomy tube around the duodenal loop because of the experience in Case 1 of the feedings coming out through the esophageal fistula. This did not prevent leakage of significant amounts of gastrostomy feedings to the esophagocutaneous fistula, however, along with large amounts of saliva and gastric juice. He went steadily downhill with a course characterized by rapid weight loss and a toxic appearance despite supportive care by a large staff and an additional drainage procedure to ensure that no areas of inadequate drainage were present. It became evident that this man was going to die as the first patient had unless some radical step could be taken to exclude the fistula.

Finally, on Sept. 1, 1954, nearly six weeks after the spontaneous perforation of the esophagus, the esophagogastric junction was divided through a left subcostal incision and both ends were sutured. This resulted in considerable decrease in the amount of drainage from the fistula tract and the temperature came down somewhat. He still had persistent fever and considerable drainage and despite our hopes that it might be avoided, the lower cervical esophagus was divided about ten days later, with suture of the distal end and exteriorization of the proximal end as an external esophagostomy just above the left clavicle. The amount of drainage from the fistula tract then decreased in a most dramatic fashion and his temperature gradually returned to normal.

He left the hospital on Oct. 22, 1954, approximately three months after the onset of his illness, to gain strength and weight in preparation for esophageal reconstruction at a later date. Prior to discharge it was established that there was a bronchopleural fistula on the left which appeared to be largely responsible for occasional low grade fever accompanied by wheezing and rales in the left lung. Because of persistence of these signs and symptoms and the threat believed to be inherent in persistence of the bronchopleural fistula, the remaining segment of the thoracic esophagus, including the original site of rupture, was excised on May 5, 1955, nearly ten months after the first operation. The esophagus was found to be distended with about 300 c.c. of purulent material identical in nature to the drainage material which had been persisting from the wound. The bronchial fistula was not visualized at operation but complete healing, following removal of d [illegible] tul curred a short time after this procedure. The patient continued to do until about six months later for esophageal reconstruction. In the meantime he had lived a comfortable and relatively normal life with his gastrostomy and external esophagostomy.

On Sept. 28, 1955, a jejunal loop prepared by the Roux-Y principle was brought up behind the sternum to the lower cervical region. There was no tension and the blood supply appeared to be entirely satisfactory after observation for one-half an hour. There were no difficulties following this procedure and three months later the cervical esophagus was anastomosed to the jejunal loop in the neck. Healing again was uneventful but the patient had intermittent diarrhea. This was overcome by connecting the new esophagus (jejunal loop) to the stomach, allowing his food once more to have a normal course through the stomach. He is now apparently restored to normal health.

Case 3.—S. Z., a 40-year-old man, was brought to the Hospital of the University of Pennsylvania on Nov. 13, 1954, within a relatively short time following the typical symptoms and signs of spontaneous perforation of the esophagus. The esophageal rent on the left lateral wall, about three inches above the diaphragm and ¾ of an inch long, was closed by a meticulous suture technique about six hours after the onset. In spite of the favorable time factor, a virulent infection developed, including empyema of the right pleural cavity, and the suture line broke down with the development of a persistent fistula, as in the other 2 patients, despite adequate drainage of both pleural cavities. This patient presented the same picture of loss of gastrostomy feedings as well as large amounts of gastric and salivary juices through the fistula tract, rather rapid loss of weight, and increasing toxicity. The fistula-containing esophageal segment was excluded, as in the previous patient, by dividing the esophagogastric junction and the lower portion of the cervical esophagus seventeen and fifty-five days, respectively, after spontaneous perforation occurred. The fever subsided and the patient showed a steady weight gain.

Several months later, after he had gained five pounds, he was readmitted to the hospital and, on June 24, 1955, a jejunal limb was brought up to the neck retrosternally as previously described. The mesenteric vessels were not quite as long in this instance, however, and the color of the most cephalad portion of the jejunal limb did not remain good unless it was allowed to recede a short distance below the suprasternal notch. At the final stage, performed on Sept. 20, 1955, difficulty in approximating this end of the jejunum to the exteriorized upper esophageal segment was anticipated but the two ends came together quite readily after only a moderate amount of mobilization. There was a small amount of leakage from the suture line for a short time but this caused no difficulties and, at the present time, he is swallowing entirely satisfactorily with maintenance of adequate weight and a normal nutritional status, although his food does by-pass the stomach.

The drainage tract leading from the esophageal fistula in this patient finally healed on Nov. 25, 1955, and there has been no evidence of formation of a mediastinal collection or cystic dilatation of the esophageal remnant as evidenced by x-ray examination.

COMMENT

The principle of exclusion has long been applied to the treatment of fistulas of other portions of the intestinal tract, particularly of the colon, following wounds or ruptured diverticulitis. It now seems reasonable to us that exclusion of a fistula of the lower thoracic esophagus is even more important than elsewhere in the gastrointestinal tract. The mediastinum and the empyema cavity are apt to be the site of very virulent infection because of the continuing soilage by pathogenic organisms and the enzymatic and chemical action of the saliva and gastric juice. These patients have become more rapidly depleted than those with gastric or duodenal fistulas, probably because of the large amount of protein lost from the infected pleural surfaces, plus the toxicity of the virulent pleural infection which is constantly kept activated by additional organisms In addition, there may, of course, be enormous losses of water and essential electrolytes of the saliva and gastric juices Greater or lesser amounts of gastrostomy feedings also came out through the fistulous tract in spite of efforts to pass the gastrostomy tube around the duodenal loop in all three instances

Hesitation in performing the exclusion procedure caused some delay in all 3 patients When first considered, the permanency of procedures which completely exclude the involved esophageal segment, and the difficulties of later esophageal construction are impressive barriers We have become convinced, however, that when a patient begins to slip with the characteristic signs and symptoms noted in these 3 patients, the radical course which we have outlined should be undertaken in spite of the evident disadvantages and prolonged discomfort which accompany the multiple operations The fistula is excluded by dividing the stomach at its junction with the esophagus and suturing both ends A gastrostomy is performed at the same time for feeding The saliva is diverted away from the fistula by dividing the esophagus in the lower cervical area, closing the distal end and bringing out the proximal end as an external cervical esophagostomy

A number of reconstructive procedures are now available[2-4] and sufficient experience has accumulated so that they may be undertaken with reasonable confidence that the outcome will be successful Stomach jejunum or colon may be used for esophageal replacement with the latter two being preferable to the former It now seems feasible to reconstruct the esophagus behind the sternum in most instances rather than antethoracically although a certain risk of necrosis of the segment which is advanced up to the neck is always present With proper judgment, skill, and experience this risk can probably be kept at a very low level

If a jejunal loop, utilizing the Roux Y principle is brought up to the cervical esophagus, nutrition may not be adequately maintained in an occasional patient unless the substitute esophagus is anastomosed to the stomach

Whether it is necessary to remove the patient's esophageal segment including the fistula has not been definitely established Animal experiments suggest that it may not be necessary, at least in some instances[5]

CONCLUSIONS

1 Following spontaneous perforation of the esophagus, a persistent esophagocutaneous fistula may result, despite adequate drainage, if the fistula is not sutured or if the suture line breaks down

2 Under such circumstances adequate drainage of the lower portion of the pleural cavity with application of suction may lead to healing of the fistula in some instances In some patients, however, the fistula will persist in spite of adequate drainage

3 When there is a persistent fistula the patient has a virulent empyema constantly bathed with salivary and gastric juices and he becomes rapidly

Five, repeat, five copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 600 South Kingshighway, St. Louis 10, Missouri.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. Karl P. Klassen, The Ohio State University, Columbus 10, Ohio, before Dec. 15, 1956.

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions. If the films are well labeled, it will not be necessary for the author to be present for comment.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec. 15, 1956, otherwise the application will be deferred for consideration until the 1958 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. O. T. Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn.

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year. The new letters of recommendation should also be sent to Dr. Clagett, the Chairman of the Membership Committee.

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